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AVIATION
ELECTRONICS TECHNICIAN 1 & C

NAVAL TRAINING COMMAND

RATE TRAINING MANUAL NAVTRA 10318-D

PREFACE

This Rate Training Manual is one of a series of Rate Training Manuals prepared especially for enlisted personnel of the Navy and Naval Reserve who are preparing for advancement to AT1 and ATC.

The Manual of Qualifications for Advancement, NavPers 18068-C, has been used as a guide in the selection of content for this manual and is current through change 0. Trainees should become familiar with the qualifications for advancement prior to starting work on this manual.

All qualifications for advancement are not covered in this manual. The following Rate Training Manuals contain essential information, some of which is background information for the study of this manual.

Basic Electronics Vol. 1, NavPers 10087-C, chapters 5, 10, 12 through 17, and 28.

Basic Electronics Vol. 2, NavPers 10087-C, chapters 7 and 8.

Synchro, Servo, and Gyro Fundamentals, NavPers 10105, chapters 3 and 4.

Digital Computer Basics, NavPers 10088, chapters 8, 9, and 10.

Military Requirements for PO 1 & C, NavPers 10057-C, chapter 10.

This Rate Training Manual has been prepared by the Navy Training Publications Center, NAS Memphis, Millington, Tennessee, for the Naval Training Command. Credit is given to the Naval Air Technical Training Center, located at NAS Memphis, Millington, Tennessee; the Naval Examining Center, Great Lakes, Illinois; the Naval Aviation Integrated Support Center, Patuxent River, Maryland; and the Naval Air Systems Command for technical reviews.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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READING LIST

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Educational Services Officer.* The following courses are recommended:

D-166 Advanced Algebra

D-177 Geometry II

D-188 Trigonometry

E-291 Physics II

A-424 Intermediate College Algebra

C-517 College Physics

F-544 Personnel Management

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more".

CREDITS

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CHAPTER 1

AVIATION ELECTRONICS TECHNICIAN RATING

This Rate Training Manual is designed to aid the AT2 in preparing for advancement to AT1 and the AT1 in preparing for advancement to ATC. It is based primarily on the professional requirements or qualifications for AT1 and ATC as specified in the Manual of Qualifications for Advancement, NavPers 18068 (Series). In preparing for advancement examinations, this manual should be studied in conjunction with the professionally related training manuals listed in the next paragraph and with Military Requirements for Petty Officer 1 & C, NavPers 10057 (Series). Any changes in the professional qualifications occurring after change O to NavPers 18068-C may not be reflected in the information presented in this Rate Training Manual.

This manual does not contain coverage on all "quals" listed in the "Quals" Manual. Some of the professional "quals" listed are wholly or partially covered by the following basic Rate Training Manuals:

Basic Electronics Vol. I, NavPers 10087-C.

Basic Electronics Vol. II, NavPers 10087-C, Chapters 7 and 8.

Digital Computer Basics, NavPers 10088, Chapters 8, 9 and 10.

Synchro, Servo and Gyro Fundamentals, NavPers 10105, Chapters 3 and 4.

Military Requirements for PO 1 & C, NavPers 10057-C, Chapter 10.

ENLISTED RATING STRUCTURE

The present enlisted rating structure includes two types of ratings: general ratings and service ratings.

GENERAL RATINGS are designed to provide paths of advancement and career development. A general rating identifies a broad occupational field of related duties and functions requiring similar aptitudes and qualifications. General ratings provide the primary means used to identify billet requirements and personnel qualifications. Some general ratings include service ratings; others do not. Both Regular Navy and Naval Reserve personnel may hold general ratings.

Subdivisions of certain general ratings are identified as SERVICE RATINGS. These service ratings identify areas of specialization within the scope of a general rating. Service ratings are established in those general ratings in which specialization is essential for efficient utilization of personnel. Although service ratings can exist at any petty officer level, they are most common at the PO3 and PO2 levels. Both Regular Navy and Naval Reserve personnel may hold service ratings.

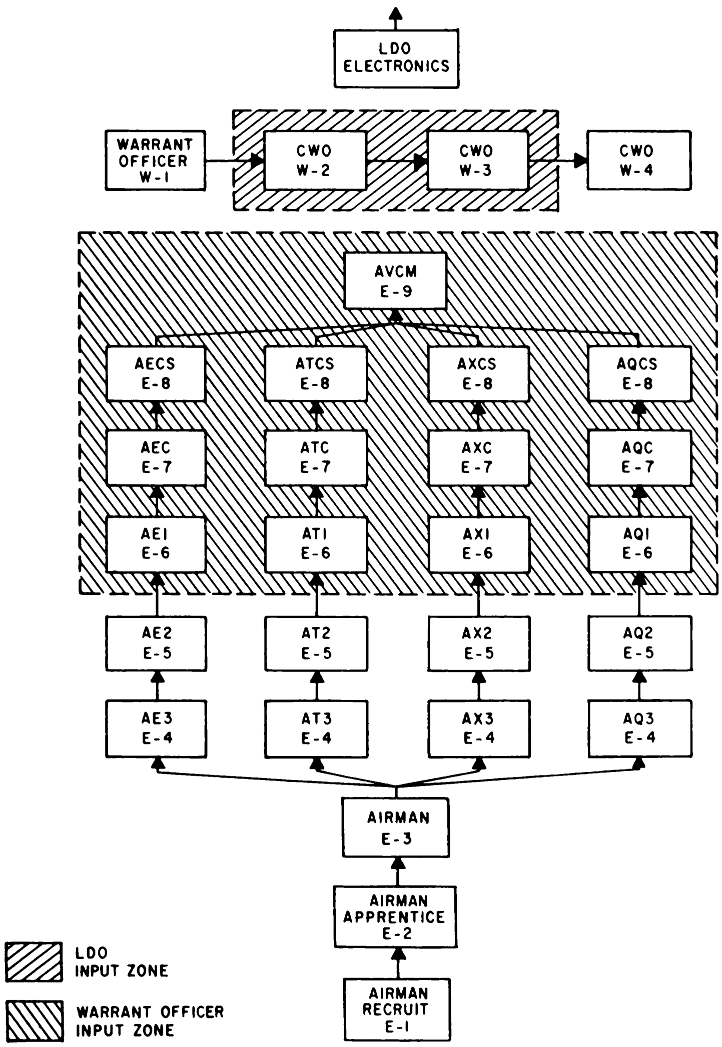
AT RATING

The Aviation Electronics Technician rating is a general rating, and is included in Navy Occupational Group IX (Aviation). There are no AT service ratings.

Where occupational content is related, general ratings have been combined at certain pay grades to form broader occupational fields. In the case of the AT rating, this takes place at the E-9 level. Here, the AT rating loses its identity and personnel in this rating advance along with ATCS, AQCS, and AXCS to Master Chief Avionics Technician (AVCM). Figure 1-1 illustrates the paths of advancement from Airman Recruit to Master Chief Avionics Technician, Warrant Officer (W-4), or Limited Duty Officer. The advancement path through the AT rating is emphasized in the illustration.

DUTIES

The Manual of Qualifications for Advancement, NavPers 18068 (Series), states that AT's inspect and perform organizational and



AE.1

Figure 1-1.—Paths of advancement.

intermediate maintenance on aviation electronic equipment, including the following:

1. Detection, reconnaissance, identification, communication, navigation, display, and special purpose equipment.

2. Target drone and pilotless aircraft equipment.

In addition to these duties, the AT's responsibilities include the operation of airborne CIC and electronic warfare (ECM) equipment.

The ATI or ATC, working in a supervisory position, is required to review and evaluate completed inspection forms and reports; analyze reports of discrepancies and malfunctions and determine corrective action; schedule and assign workloads; determine repair procedures for aircraft electronic equipment; and maintain quality control of work performed.

When advanced to AT1 or ATC, even more responsibilities are to be yours. As a senior petty officer, you must possess more than technical knowledge. You must assume greater responsibility not only for your own work, but also for the work of others who serve under you. The AT1 and ATC must be a supervisor, inspector, and instructor, as well as an accomplished military leader. Senior petty officers should therefore be vitally concerned with the Naval Leadership Program.

As a result of the Naval Leadership Program, a considerable amount of material related to naval leadership for the senior petty officer is available. Studying this material will make you aware of your many leadership responsibilities as a senior petty officer and will also be of great help in developing leadership qualities. It will not in itself, however, make you a good leader. Leadership principles can be taught, but a good leader acquires that quality only through hard work and practice.

As you study this material containing leadership traits, keep in mind that probably none of our most successful leaders possessed all of these traits to a maximum degree, but a weakness in some traits was more than compensated for by strength in others. Critical self-evaluation will enable you to realize the traits in which you are strong, and to capitalize on them. At the same time you must strive to improve on the traits in which you are weak.

Your success as a leader will be decided, for the most part, by your achievements in inspiring others to learn and perform. This is best accomplished by personal example.

BILLETS

A wide variety of assignments is available to the AT1 and ATC. In addition to the various types of maintenance activities to which lower rated personnel are assigned (discussed in AT3 and 2, NavPers 10317-D, the AT1 and ATC are eligible for assignment to instructor duty as well as a number of other desirable shore billets. Most of these billets are under the management control of BuPers and are directly associated with training. Others are associated with research, testing, or evaluation. Some of the more desirable billets to which the AT1 and ATC may be assigned are described in the following paragraphs.

Instructor duty is available to both the AT1 and the ATC at the Naval Air Technical Training Center, Millington, Tennessee, in the following schools:

1. Avionics Technician Course (Class A).
2. Advanced First Term Avionics Course (Class B).
3. Avionics Intermediate Course (Class B).
4. Avionics Advanced Course (Class B).
5. Aviation Officers School (Class O).

In addition to the above listed instructor billets, the AT1 and ATC may be assigned to instructor duty with a Naval Air Maintenance Training Detachment (NAMTD). NAMTD's are located at shore stations on both coasts. Personnel assigned to this duty are first sent to Naval Air Maintenance Training Group headquarters at Millington, Tennessee, for a period of indoctrination and instruction.

Instructor billets are normally filled on a voluntary basis. Detailed information concerning assignment to instructor duty is contained in the Enlisted Transfer Manual, NavPers 15909 (Series).

Chief Aviation Electronics Technicians are eligible for assignment to duty with the Navy Training Publications Center (NTPC), NAS, Millington, as Technical Writers. CPO's assigned to NTPC assist in the preparation and revision of Rate Training Manuals for the Group IX (Aviation) ratings. AT's assigned to these billets assist in preparing and/or revising Rate Training Manuals for the avionics ratings.

Chief Aviation Electronics Technicians are also eligible for assignment to duty with the Naval Examining Center, Great Lakes, Illinois, as Item Writers. COP's assigned to the Examining Center assist in the preparation of Navywide advancement examinations for enlisted personnel. AT's assigned to these billets assist in preparing examinations for the AT ratings.

There are a number of special programs and projects to which enlisted personnel may be assigned. For a listing of these special programs and projects, reference should be made to the Enlisted Transfer Manual. Others are also announced from time to time in BuPers Notices.

Personnel may indicate their desire for assignment to a specific program or project by indicating it in the "remarks" block of their Rotation Data Card.

As a petty officer, you are already aware of the importance of the AT rating to naval aviation. Pilots and aircrewmen depend upon the AT for the efficient operation of the avionics system for which he is responsible. As improved electronic systems are developed, the AT's job involves new and greater responsibilities; from the lowest level up, he must possess greater technical skills than ever before.

ADVANCEMENT

By this time, you are probably well aware of the personal advantages of advancement—higher pay, greater prestige, more interesting and challenging work, and the satisfaction of getting ahead in your chosen career. By this time, also, you have probably discovered that one of the most enduring rewards of advancement is the training you acquire in the process of preparing for advancement.

The Navy also profits by your advancement. Highly trained personnel are essential to the functioning of the Navy. By advancement, you increase your value to the Navy in two ways: First, you become more valuable as a technical specialist, and thus make far-reaching contributions to the entire Navy; and second, you become more valuable as a person who can supervise, lead, and train others.

Since you are studying for advancement to PO1 or CPO, you are probably already familiar with the requirements and procedures for advancement. However, you may find it helpful to read the following sections. The Navy does not stand still. It is possible that some of the requirements have changed since the last time you went up for advancement. Furthermore, you will be responsible for training others for advancement; therefore, you will need to know the requirements in some detail.

HOW TO QUALIFY FOR ADVANCEMENT

To qualify for advancement, a person must:

1. Have a certain amount of time in grade.
2. Complete the required Rate Training Manuals either by demonstrating a knowledge of the material in the manual by passing a locally prepared and administered test or by passing the Enlisted Correspondence Course based on the Rate Training Manual.
3. Demonstrate the ability to perform all the PRACTICAL requirements for advancement by completing applicable portions of the Record of Practical Factors, NavPers 1414/1.
4. Be recommended by his commanding officer, after the petty officers and officers supervising the work have indicated that they consider him capable of performing the duties of the next higher rate.
5. Demonstrate KNOWLEDGE by passing a written examination on (a) military requirements, and (b) professional qualifications.

Some of these general requirements may be modified in certain ways. Figure 1-2 gives an overall view of the requirements for advancement of active duty personnel; figure 1-3 gives this information for inactive duty personnel.

Remember that the requirements for advancement can change. Check with your educational services office to be sure that you know the most recent requirements.

When you are training lower rated personnel, it is a good idea to point out that advancement is not automatic. Meeting all the requirements makes a person ELIGIBLE for advancement, but it does not guarantee his advancement. Such factors as the score made on the written examination, length of time in service, performance marks, and quotas for the rating enter into the final determination of who will actually be advanced.

HOW TO PREPARE FOR ADVANCEMENT

What must you do to prepare for advancement? You must study the qualifications for advancement, work on the practical factors, study the required Rate Training Manuals, and study other material that is required. You will need to be familiar with the following:

1. Manual of Qualifications for Advancement, NavPers 18068 (Series).
2. Record of Practical Factors, NavPers 1414/1.
3. Bibliography for Advancement Study, NavPers 10052 (Series).
4. Applicable Rate Training Manuals and their companion Enlisted Correspondence Courses.

Collectively, these documents make up an integrated training package tied together by the qualifications. The following paragraphs describe these materials and give some information on how each one is related to the others.

"Quals" Manual

The Manual of Qualifications for Advancement, NavPers 18068 (Series), gives the minimum requirements for advancement to each rate within each rating. This manual is usually called the "Quals" Manual, and the qualifications themselves are often called "quals." The qualifications are of two general types: (1) military requirements, and (2) professional or technical qualifications. Military requirements apply to all ratings rather than to any one rating alone. Professional qualifications are technical or professional requirements that are directly related to the work of each rating.

Both the military requirements and the professional qualifications are divided into subject matter groups. Then, within each subject matter group, they are divided into PRACTICAL FACTORS and KNOWLEDGE FACTORS.

REQUIREMENTS*	E1 to E2	E2 to E3	#† E3 to E4	#E4 to E5	† E5 to E6	† E6 to E7	† E7 to E8	† E8 to E9
SERVICE	4 mos. service—or completion of	6 mos. as E-2.	6 mos. as E-3	12 mos. as E-4	24 mos. as E-5.	36 mos. as E-6. 8 years total enlisted service.	36 mos as E-7. 8 of 11 years total service must be enlisted.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, DT3,PT3, AME 3, HM 3, PN 3, FTB 3, MT 3,			Class B for AGC MUC, MNC.††		
PRACTICAL FACTORS	Locally prepared check-offs.	Record of Practical Factors, NavPers 1414/1, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS**	Locally prepared tests.	See below.	Navy-wide examinations required for all PO advancements.				Navy-wide, selection board.	
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavPers 10052 (current edition).					Correspondence courses and recommended reading. See NavPers 10052 (current edition).	
AUTHORIZATION	Commanding Officer		Naval Examining Center					

* All advancements require commanding officer's recommendation.
† 1 year obligated service required for E-5 and E-6; 2 years for E-7, E-8 and E-9.
# Military leadership exam required for E-4 and E-5.
** For E-2 to E-3, NAVEXAMCEN exams or locally prepared tests may be used.
†† Waived for qualified EOD personnel.

Figure 1-2.—Active duty advancement requirements.

REQUIREMENTS *	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
TOTAL TIME IN GRADE	4 mos.	6 mos.	6 mos.	12 mos.	24 mos.	36 mos. with total 8 yrs service	36 mos. with total 11 yrs service	24 mos. with total 13 yrs service
TOTAL TRAINING DUTY IN GRADE †	14 days	14 days	14 days	14 days	28 days	42 days	42 days	28 days
PERFORMANCE TESTS			Specified ratings must complete applicable performance tests before taking examination.					
DRILL PARTICIPATION	Satisfactory participation as a member of a drill unit in accordance with BUPERSINST 5400.42 series.							
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)	Record of Practical Factors, NavPers 1414/1, must be completed for all advancements.							
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIRE MENTS)	Completion of applicable course or courses must be entered in service record.							
EXAMINATION	Standard Exam		Standard Exam required for all PO Advancements. Also pass Military Leadership Exam for E-4 and E-5.				Standard Exam, Selection Board.	
AUTHORIZATION	Commanding Officer		Naval Examining Center					

* Recommendation by commanding officer required for all advancements.

† Active duty periods may be substituted for training duty.

Figure 1-3.—Inactive duty advancement requirements

The qualifications for advancement and a bibliography of study materials are available in your educational services office. The "Quals" Manual is changed more frequently than Rate Training Manuals are revised. By the time you are studying this training manual, the "quals" for your rating may have been changed. Never trust any set of "quals" until you have checked the change number against an UP-TO-DATE copy of the "Quals" Manual.

In training others for advancement, emphasize these three points about the "quals":

1. The "quals" are the MINIMUM requirements for advancement. Personnel who study MORE than the required minimum will have a great advantage when they take the written examinations for advancement.
2. Each "qual" has a designated rate level-chief, first class, second class, or third class. You are responsible for meeting all "quals" specified for the rate level to which you are seeking advancement AND all "quals" specified for lower rate levels. This manual is written to provide additional or add-on information to that contained in AT 3 & 2, NavPers 10317-OD, and it is recommended that the material in this 3 & 2 manual be reviewed.
3. The written examinations for advancement will contain questions relating to the practical factors AND to the knowledge factors of BOTH the military requirements and the professional qualifications.

Record of Practical Factors

Before you can take the Navy-wide examination for advancement, there must be an entry in your service record to show that you have qualified in the practical factors of both the military requirements and the professional qualifications. A special form known as the Record of Practical Factors, NavPers 1414/1 (plus the abbreviation of the appropriate rating), is used to keep a record of your practical factor qualifications. The form lists all practical factors, both military and professional. As you demonstrate your ability to perform each practical factor, appropriate entries are made in the DATE and INITIALS columns.

As a PO1 or CPO, you will often be required to check the practical factor performance of lower rated personnel and to report the results to your supervising officer.

As changes are made periodically to the "Quals" Manual, new forms of NavPers 1414/1 are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in changes to the "Quals" Manual. The Record of Practical Factors also provides space for recording demonstrated proficiency in skills which are within the general scope of the rating but which are not identified as minimum qualifications for advancement. Keep this in mind when you are training and supervising other personnel. If a person demonstrates proficiency in some skill which is not listed in the "quals" but which is within the general scope of the rating, report this fact to the supervising officer so that an appropriate entry can be made in the Record of Practical Factors.

When you are transferred, the Record of Practical Factors should be forwarded with your service record to your next duty station. It is a good idea to check and be sure that this form is actually inserted in your service record before you are transferred. If the form is not in your record, you may be required to start all over again and requalify in practical factors that have already been checked off. You should also take some responsibility for helping lower rated personnel keep track of their practical factor records when they are transferred.

A second copy of the Record of Practical Factors should be made available to each man in pay grades E-2 through E-8 for his personal record and guidance.

The importance of NavPers 1414/1 cannot be over-emphasized. It serves as a record to indicate to the petty officers and officers supervising your work that you have demonstrated proficiency in the performance of the indicated practical factors and is part of the criteria utilized by your commanding officer when he considers recommending you for advancement. In addition, the proficient demonstration of the applicable practical factors listed on this form can aid you in preparing for the examination for advancement. Remember that the knowledge aspects of the practical factors are covered in the examination for advancement. Certain knowledge is required to demonstrate these practical factors and additional knowledge can be acquired during the demonstration. Knowledge factors pertain to that knowledge which is required to perform a certain job. In other words, the knowledge factors required for a certain rating depend upon the jobs (practical factors) that must be performed by personnel of that rating. Therefore, the knowledge required to proficiently demonstrate these practical factors will definitely aid you in preparing for the examination for advancement.

NavPers 10052

Bibliography for Advancement Study, NavPers 10052 (Series) is a very important publication for anyone preparing for advancement. This publication/bibliography lists required and recommended Rate Training Manuals and other reference material to be used by personnel working for advancement. NavPers 10052 (Series) is revised and issued once each year by the Bureau of Naval Personnel. Each revised edition is identified by a letter following the NavPers number; be SURE you have the most recent edition.

The required and recommended references are listed by rate level in NavPers 10052 (Series). It is important to remember that you are responsible for all references at lower rate levels, as well as those listed for the rate to which you are seeking advancement.

Rate Training Manuals that are marked with an asterisk (*) in NavPers 10052 (Series) are MANDATORY at the indicated rate levels. A mandatory training manual may be completed by (1) passing the appropriate Enlisted Correspondence Course that is based on the mandatory training manual; (2) passing locally prepared tests based on the information given in the mandatory training manual; or (3) in some cases, successfully completing an appropriate Navy school.

When training personnel for advancement, do not overlook the section of NavPers 10052 (Series) which lists the required and recommended references relating to the military requirements for advancement. All personnel must complete the mandatory military requirements training manual for the appropriate rate level before they can be eligible to advance. Also, make sure that personnel working for advancement study the references listed as recommended but not mandatory in NavPers 10052 (Series). It is important to remember that ALL references listed in NavPers 10052 (Series) are used as primary source material for the written examinations, at the appropriate levels. In addition, any reference made in the primary source material to other material (instructions, manuals, etc.) may be used as secondary source material for the written examination.

Rate Training Manuals

There are two general types of Rate Training Manuals. Rate Training Manuals (such as this one) are prepared for most enlisted rates and ratings, giving information that is directly related to the professional qualifications for advancement. Subject matter-manuals give information that applies to more than one rating.

Rate Training Manuals are revised from time to time to bring them up to date technically. The revision of a Rate Training Manual is identified by a letter following the NavPers number. You can tell whether a Rate Training Manual is the latest edition by checking the NavPers number (and the letter following the number) in the most recent edition of List of Training Manuals and Correspondence Courses, NavPers 10061 (Series). (NavPers 10061 is actually a catalog that lists current training manuals and correspondence courses; you will find this catalog useful in planning your study program.)

Rate Training Manuals are designed for the special purpose of helping naval personnel prepare for advancement. By this time, you have probably developed your own way of studying these manuals. Some of the personnel you train, however, may need guidance in the use of Rate Training Manuals. Although there is no single "best" way to study a training manual, the following suggestions have proved useful for many people:

1. Study the military requirements and the professional qualifications for your rate before you study the training manual, and refer to the "quals" frequently as you study. Remember, you are studying the training manual primarily to meet these "quals."
2. Set up a regular study plan. If possible, schedule your studying for a time of day when you will not have too many interruptions or distractions.
3. Before you begin to study any part of the training manual intensively, get acquainted with the entire manual. Read the preface and the table of contents. Check through the index. Thumb through the manual without any particular plan, looking at the illustrations and reading bits here and there as you see things that interest you.
4. Look at the training manual in more detail, to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a clear picture of the scope and content of the manual.
5. When you have a general idea of what is in the training manual and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit—it

may be a chapter, a section of a chapter, or a subsection. The amount of material you can cover at one time will vary. If you know the subject well, or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more study time.

6. In studying each unit, write down questions as they occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

7. As you study, relate the information in the training manual to the knowledge you already have. When you read about a process, a skill, or a situation, ask yourself some questions. Does this information tie in with past experience? Or is this something new and different? How does this information relate to the qualifications for advancement?

8. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without referring to the training manual, write down the main ideas you have learned from studying this unit. Do not just quote the manual. If you cannot give these ideas in your own words, the chances are that you have not really mastered the information.

9. Use Enlisted Correspondence Courses whenever you can. The correspondence courses are based on Rate Training Manuals or other appropriate texts. As mentioned before, completion of a mandatory Rate Training Manual can be accomplished by passing an Enlisted Correspondence Course based on the training manual. You will probably find it helpful to take other correspondence courses, as well as those based on mandatory training manuals. Taking a correspondence course helps you to master the information given in the training manual, and also gives you an idea of how much you have learned.

10. You should remember that occasionally reference is made in the Rate Training Manual and other primary source material to publications which contain information relative to the 10056 rating, but which are not listed in NavPers 10052 (Series). These are known as secondary references and should be reviewed in conjunction with your study of the Rate Training Manual to better prepare yourself for advancement.

INCREASED RESPONSIBILITIES

When you assumed the duties of a PO3, you began to accept a certain amount of responsibility for the work of others. With each advancement, you accept an increasing responsibility in military matters and in matters relating to the professional work of your rate. When you advance to PO1 or CPO, you will find a noticeable increase in your responsibilities for leadership, supervision, training, working with others, and keeping up with new developments.

As your responsibilities increase, your ability to communicate clearly and effectively must also increase. The simplest and most direct means of communication is a common language. The basic requirement for effective communication is therefore a knowledge of your own language. Use correct language in speaking and in writing. Remember that the basic purpose of all communication is understanding. To lead, supervise, and train others, you must be able to speak and write in such a way that others can understand exactly what you mean.

Leadership and Supervision

As a PO1 or CPO, you will be regarded as a leader and supervisor. Both officers and enlisted personnel will expect you to translate the general orders given by officers into detailed, practical, on-the-job language that can be understood and followed by relatively inexperienced personnel. In dealing with your juniors, it is up to you to see that they perform their jobs correctly. At the same time, you must be able to explain to officers any important problems or needs of enlisted personnel. In all military and professional matters, your responsibilities will extend both upward and downward.

Along with your increased responsibilities, you will also have increased authority. Officers and petty officers have POSITIONAL authority—that is, their authority over others lies in their positions. If your CO is relieved, for example, he no longer has the degree of authority over you that he had while he was your CO, although he still retains the military authority that all seniors have over subordinates. As a PO1, you will have some degree of positional authority; as a CPO, you will have even more. When exercising your authority, remember that it is positional—it is the rate you have, rather than the person you are, that gives you this authority.

A Petty Officer conscientiously and proudly exercises his authority to carry out the responsibilities he is given. He takes a personal interest in the success of both sides of the chain of command . . . authority and responsibility. For it is true that the Petty Officer who does not seek out and accept responsibility, loses his authority and then the responsibility he thinks he deserves. He must be sure, by his example and by his instruction, that the Petty Officers under him also accept responsibility. In short, he must be the leader his title—Petty Officer—says he is.

Training

As a PO1 or CPO, you will have regular and continuing responsibilities for training others. Even if you are lucky enough to have a group of subordinates who are all highly skilled and well trained, you will still find that training is necessary. For example, you will always be responsible for training lower rated personnel for advancement. Also, some of your best workers may be transferred; and inexperienced or poorly trained personnel may be assigned to you. A particular job may call for skills that none of your personnel have. These and similar problems require that you be a training specialist—one who can conduct formal and informal training programs to qualify personnel for advancement, and one who can train individuals and groups in the effective execution of assigned tasks.

In using this training manual study the information from two points of view. First, what do you yourself need to learn from it? And second, how would you go about teaching this information to others?

Training goes on all the time. Every time a person does a particular piece of work, some learning is taking place. As a supervisor and as a training expert, one of your biggest jobs is to see that your personnel learn the RIGHT things about each job so that they will not form bad work habits. An error that is repeated a few times is well on its way to becoming a bad habit. You will have to learn the difference between oversupervising and not supervising enough. No one can do his best work with a supervisor constantly supervising. On the other hand, you cannot turn an entire job over to an inexperienced person and expect him to do it correctly without any help or supervision.

In training lower rated personnel, emphasize the importance of learning and using correct terminology. A command of the technical languages of your occupational field (rating) enables you to receive and convey information accurately and to exchange ideas with others. A person who does not understand the precise meaning of terms used in connection with the work of his rating is definitely at a disadvantage when he tries to read official publications relating to his work. He is also at a great disadvantage when he takes the examinations for advancement. To train others in the correct use of technical terms, you will need to be very careful in your own use of words. Use correct terminology and insist that personnel you are supervising use it too.

You will find the Record of Practical Factors, NavPers 1414/1, a useful guide in planning and carrying out training programs. From this record, you can tell which practical factors have been checked off and which ones have not yet been done. Use this information to plan a training program that will fit the needs of the personnel you are training.

On-the-job training is usually controlled through daily and weekly work assignments. When you are working on a tight schedule, you will generally want to assign each person to the part of the job that you know he can do best. In the long run, however, you will gain more by assigning personnel to a variety of jobs so that each person can acquire broad experience. By giving people a chance to do carefully supervised work in areas in which they are relatively inexperienced, you will increase the range of skills of each person and thus improve the flexibility of your working group.

Working With Others

As you advance to PO1 or CPO, you will find that many of your plans and decisions affect a large number of people, some of whom are not even in your own occupational field (rating). It becomes increasingly important, therefore, for you to understand the duties and the responsibilities of personnel in other ratings. Every petty officer in the Navy is a technical specialist in his own field. Learn as much as you can about the work of others, and plan your own work so that it will fit into the overall mission of the organization.

Keeping Up With New Developments

Practically everything in the Navy—policies, procedures, publications, equipment, systems—

is subject to change and development. As a PO1 or CPO, you must keep yourself informed about changes and new developments that affect you or your work in any way.

Some changes will be called directly to your attention, but others will be harder to find. Try to develop a special kind of alertnes for new information. When you hear about anything new in the Navy, find out whether there is any way in which it might affect the work of your rating. If so, find out more about it.

SOURCES OF INFORMATION

As a PO1 or CPO, you must have an extensive knowledge of the references to consult for accurate, authoritative, up-to-date information on all subjects related to the military and professional requirements for advancement.

Publications mentioned in this chapter are subject to change or revision from time to time—some at regular intervals, others as the need arises. When using any publication that is subject to revision, make sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made.

The reading list at the beginning of this manual consists of USAFI courses that offer additional background material. The educational services officer will always have the most up-to-date information and training manuals applicable to your rating.

In addition to training manuals and publications, training films furnish a valuable source of supplementary information. Films that may be helpful are listed in the U.S. Navy Film Catalog, NavAir 10-1-777.

ADVANCEMENT OPPORTUNITIES FOR PETTY OFFICERS

Making chief petty officer is not the end of the line as far as advancement is concerned. Proficiency pay, advancement to Senior (E-8) and Master (E-9) Chief, and advancement to Warrant Officer and Commissioned Officer are among the opportunities that are available to qualified petty officers. These special paths of advancement are open to personnel who have demonstrated outstanding professional ability, the highest order of leadership and military responsibility, and unquestionable moral integrity.

PROFICIENCY PAY

The Career Compensation Act of 1949, as amended, provides for the award of Proficiency Pay to designated military specialities. Proficiency Pay is given in addition to regular pay and allowances and any special or incentive pay to which you are entitled. Certain enlisted personnel in pay grades E-4 through E-9 are eligible for Proficiency Pay. Proficiency Pay is awarded in two categories: (1) Shortage Speciality Pay—to designated ratings and NEC's, and (2) Special Duty Assignment Pay—for duty in certain critical special duty assignments not covered by Shortage Specialty Pay. The eligibility requirements for Proficiency Pay are subject to change. In general, however, you must be recommended by your commanding officer, have a certain length of time on continuous active duty, and be career designated.

ADVANCEMENT TO SENIOR AND MASTER CHIEF

Chief Petty Officers may qualify for the advanced grades of Senior and Master Chief Petty Officer which are now provided in the enlisted pay structure. These advanced grades provide for substantial increases in pay, together with increased responsibilities and additional prestige. The requirements for advancement to Senior and Master Chief Petty Officer are subject to change but, in general, include a certain length of time in grade, a certain length of time in the naval service, a recommendation by the commanding officer, and a sufficiently high mark on the Navy-wide examination. The final selection for Senior and Master Chief Petty Officer is made by a regularly convened selection board.

Examination Subjects

Qualifications for advancement to Senior Chief Petty Officer and Master Chief Petty Officer have been developed and published in the Manual of Qualifications for Advancement, NavPers 18068 (Series). They officially establish minimum military and professional qualifications for Senior and Master Chief Petty Officers.

Bibliography for Advancement Study NavPers 10052 (Series) contains a list of study references which may be used to study for both military and professional requirements.

The satisfactory completion of the correspondence course titled Navy Regulations, NavPers 10740-A4, is mandatory for advancement to E-8, and the course titled Military Justice in the Navy, NavPers 10993-A, is required of all personnel advancing to E-9.

ADVANCEMENT TO WARRANT AND COMMISSIONED OFFICER

The Warrant Officer program provides opportunity for advancement to warrant rank for E-6 and above enlisted personnel. E-6's, to be eligible, must have passed an E-7 rating exam prior to selection.

The LDO program provides a path of advancement from warrant officer to commissioned officer. LDO's are limited, as are warrants, in their duty, to the broad technical fields associated with their former rating.

If interested in becoming a warrant or commissioned officer, ask your educational services officer for the latest requirements that apply to your particular case.

CHAPTER 2

AVIONICS MAINTENANCE MANAGEMENT

The job of supervising the operation of a division or work center is a many sided task. Some of the techniques will have been learned through past experience. Others may be learned from self-study courses and technical publications. Still other techniques will have to be learned during the actual supervision of the division or shop. The purpose of this chapter is to acquaint the new supervisor with some of the more important aspects of shop supervision.

OBJECTIVES OF SUPERVISION

Briefly, the objectives of supervision are as follows:

1. To operate with maximum efficiency and safety.
2. To operate with minimum expense and waste.
3. To operate free from interruption and difficulty.

While these are the primary objectives of shop supervision, it is well for the man who may be assigned these duties to keep in mind the fact that his new assignment is important to him personnally, since it affords him in an excellent opportunity to gain practical experience toward future promotions.

OPERATION WITH MAXIMUM EFFICIENCY AND SAFETY

The operational efficiency of a work center is dependent to a large extent upon how conveniently the work spaces and equipment are arranged in the work center and upon the extent to which the work center, files, and equipment are maintained. Equipment in good working order, tools in good shape and of the proper type and quantity, and an up-to-date file of applicable publications are all important factors toward a smoothly running work center.

As some equipment becomes obsolete and new equipments and new models of equipment are phased into the work center inventory, the efficiency will increase to a certain extent, but may still be short of the full potential. Making a drastic rearrangement to improve the utilization of a single piece of equipment may not be economically feasible; however, a drastic change which results in improved utilization of several equipments may be worthwhile. The new shop supervisor will want to make an evaluation of the existing work center layout to assure himself that he has the most efficient arrangement possible.

The work center functions may be further smoothed by the judicious delegation of authority. The delegation of authority does not relieve the supervisor of the final responsibility for work accomplishment. It is primarily a means of relieving the supervisor of details. A supervisor who allows himself to become too involved with details loses his effectiveness as a supervisor.

A supervisor should know his men's limitations and capabilities in order to get the most work out of them. He should exploit the capabilities of his best men in a twofold manner. If at all possible he should assign a well-qualified man to do a certain job and add to the team other individuals who are less qualified but who are professionally ready for advanced on-the-job training.

The supervisor must anticipate the eventual loss of his most experienced workers through transfers, discharges, etc., and offset this by the establishment of an effective and continuing training program. In addition to raising the skill level of his division, the training program will insure that personnel, otherwise qualified, will be ready for the advancement in rating examinations.

A work center safety program must be organized and administered if the work center is function efficiently. Current Navy directives d local policies are quite specific as to the tablishment of safety training programs. A rker is not much good to anyone if he is laid in the sickbay.

The keeping of accurate and complete rec- ds is another factor in the efficient opera- n of a work center. The most efficient record- eper is one who has enough records without ving his files bulging with useless and out- ted material.

A knowledge of the principles of man-hour counting is necessary in the efficient utiliza- n of the manpower available. The supervisor ould schedule his workload in such a way that anned absences of key workers will not un- ly interrupt the daily routine. When schedul- the workload, he should keep in mind the ill level required for the various tasks and sign individuals to jobs in such a way that the rk may still progress if any worker is un- pectedly absent.

PERATION WITH MINIMUM XPENSE AND WASTE

The efficiency of any operation is directly lated to the expense involved. The work cen- supervisor has responsibility for ordering d accounting for parts and materials. He must press upon his men the need for being thrifty the use of these materials. There are many ys to economize, and the supervisor and his nior petty officers should always be on the ert for opportunities to point out these ways the less experienced individuals.

Methods of avoiding waste and unnecessary pense should be included in the work center ining program.

ROVIDING FOR INTERRUPTION

During an average workday, occasions will ise when personnel have to leave their work- spaces for one reason or another, thereby laying the scheduled work. Some delays can anticipated; some cannot. Among the de- s that can be anticipated are training lec- es, immunization schedules, flight schedules, ing examinations, meals, and watches and er military duties.

Before making personnel work assignments supervisor should determine what delays be anticipated. It may be possible to ar- nge assignments so that work interruption is held to a minimum. When estimating the completion time of a maintenance task, the supervisor should allow for these predictable delays.

UNFORESEEN DIFFICULTIES

Some difficulties are impossible to predict. The weather, for instance, cannot be relied upon for full cooperation in the maintenance effort. The supervisor must have a flexible schedule planned to provide for such events if he expects to contribute maximum support to his unit. The flight schedule itself is seldom ever completed without a few changes. Usually these changes will involve a rearrangement of previously planned maintenance tasks. Again the supervisor must be as well prepared for such interruptions as possible and be able to reassign his men, if necessary, with the least amount of confusion and loss of time.

WORK CENTER ORGANIZATION

A well-organized work center will provide a safe and comfortable working area, allow for maximum use of space available, and produce the most toward the maintenance effort.

LAYOUT

The average Chief or First Class Petty Officer may never have the opportunity of planning the layout of an avionics work center in a new facility. In almost every case, the new supervisor will take charge of an already functioning division or, when his squadron or unit moves to a new base, he and his crew will usually be assigned to spaces already basically equipped. In either case, a reevaluation of the work center's layout is indicated. This reevaluation should include checking the most recent applicable allowance lists to see if the work center equipment allowances have been changed in any way. There is no use relocating equipment which involves rewiring work if improved replacement models are authorized and available.

A change in assigned aircraft model designation may call for a reevaluation of the work center layout.

When planning for new installations, the supervisor should utilize the Design Guide for Avionics Shop Power Distribution, NavAir 01-1A-512.

The ideal setup contains enough space to have all the avionics work centers in separate spaces in a centrally located area. Since this is not always possible, the supervisor must decide what work centers are to be combined, if any, and in what areas of each space the appropriate equipment is to be installed. This decision should be based on factors of safety, economy, functional compatibility, and convenience.

The work center layout plan should make provisions for an information or bulletin board upon which may be posted safety posters, maintenance posters, instructions and notices, plans-of-the-day, and such other information as is appropriate from time to time. The bulletin board should be located in a prominent place in the work center, preferably near the entrance where everyone assigned will have to pass at some time or another during the day. Material on the bulletin board should be changed frequently, expired notices promptly removed, the current plan-of-the-day posted early, and other posters and materials rotated periodically. If the same material is presented in the same format every day, it will not be long before the men begin to ignore the bulletin board and purposes for having it are defeated. New arrangements are noticed and interest is stimulated with variety.

ARRANGEMENT

First decide what work centers are to occupy what spaces, then decide on the arrangement of the furniture and equipment within each work center.

The arrangement of the work center furnishings should be made on the basis of utility rather than appearance. Moving an item of equipment into an out-of-the-way corner may greatly improve the appearance of the work center but at the same time reduce the efficiency of personnel using the equipment and may possibly create a safety hazard. A good rule to follow is to locate equipment where it can be safely used by the greatest number of people with a minimum of effort in the least amount of time.

In view of the fact that standard avionics workbenches are normally used in work centers where actual maintenance and testing of equipments are accomplished and that these benches usually become fixed in their position (due to test harness and cabling arrangements), there will be few benches or worktables to consider. Worktables or workbenches that are not permanently installed should be positioned with respect to fixed equipment so that they can be safely, quickly, and easily reached when work is being performed that requires their use. In an area where intricate maintenance functions are to be performed, such as disassembly and repair of miniature components, consideration should be given to special interference-free type lighting.

If a separate work center space is not provided for classified equipments, then placement of these equipments in a section of the work center where the physical arrangement provides limited or controlled access is desired.

SAFETY

Operational readiness of a maximum number of aircraft is necessary if naval aviation is to successfully perform its mission. Keeping its aircraft in top operating condition is the principal function of naval aviation maintenance personnel. It is essential that maintenance work be performed with a minimum of injury to personnel and damage to equipment and aircraft.

Aircraft maintenance is, to some extent, naturally hazardous due to the nature of the work, the equipment and tools involved, and the variety of materials required to perform many repairs and maintenance functions. Factors which can function to increase or decrease these hazards are (1) the experience levels and mental attitudes of assigned personnel, and (2) the quality of supervision of the maintenance tasks. Thorough indoctrination of all personnel is the most important single step in maintaining safe working conditions.

The concept of aircraft maintenance safety should extend beyond concern for injury to personnel and damage to equipment and aircraft. Safe work habits go hand-in-hand with flying safety. Tools left in aircraft, improper torquing of fasteners, and poor housekeeping around aircraft can cause conditions which may claim the lives of flying personnel as well as cause strike damage to aircraft. Safety on the ground is equally as important as safety in the air.

A recent type commander letter states in part, "While the increased complexity of our modern aircraft is a factor, it is noted that a large number of maintenance-error-caused accidents and incidents are due, not to complexity of equipment, but to lack of supervision and technical knowledge. Many mistakes are simple ones in routine maintenance."

Safety in aircraft maintenance depends largely upon the supervisory personnel. The standards of quality which they establish are directly reflected in the quality of the aircraft maintenance. The primary duty of the senior petty officers is to supervise and instruct others rather than to become totally engrossed in actual production. Attempts to perform both functions invariably result in inadequate supervision and greater chance of error. Supervisors must exercise mature judgment when assigning personnel to maintenance jobs. Consideration must be given to each man's experience, training, and ability.

Sometimes overlooked in a maintenance program are the considerations generally grouped under the term "human factors." These factors are important in that they determine if an individual is ready and physically able to do work safely and with quality. Supervisory personnel should be constantly aware of conditions such as general health, physical and mental fatigue, unit and individual morale, training and experience levels of personnel, and other conditions which can contribute in varying degrees to unsafe work. Not only is it important that proper tools and protective clothing and equipment are available for use, but also the insistence by maintenance supervisors that they are used is of increasing importance with modern high performance aircraft. For example, maintenance personnel are sometimes negligent in the wearing of protective hearing devices in high noise areas.

There are several areas in which the work center supervisor can effectively work to minimize accidents incident to aircraft maintenance. Among these are continuing inspections of work areas, tools, and equipment; organization and administration of safety programs; correct interpretation of safety directives and precautions; and energetic and imaginative enforcement of them.

Technical knowledge also plays a large part in a good maintenance safety program. The complexity of our modern equipment demands the attention of well-informed and expert maintenance personnel; otherwise, our weapons system cannot be operated and maintained. Technical knowledge is a function of education and training which, incidentally, does not end with graduation from school. Graduation is only the beginning. Any technician worthy of his rating is continually training and learning through self-study and application, and through a personal desire for proficiency and self-betterment. But technical knowledge by itself is not sufficient unless it is coupled with an old-fashioned craftmanship that receives gratification and keen satisfaction in doing any job well. The man who wishes to contribute to safety and reliability improvement must know his job and must develop professional pride in the quality of his work.

It is a continuing duty of every person connected with aircraft maintenance to try to discover and eliminate unsafe work practices. Accidents which are caused by such practices may not take place until a much later date and their severity cannot be predicted. The consequences may range from simple material failure to a major accident resulting in serious injuries or fatalities.

ELIMINATION OF HAZARDS

Most accidents which occur in noncombat operations can be prevented if the full cooperation of personnel is gained and vigilance is exercised to eliminate unsafe acts. The supervisor should diligently inspect work areas, tools, and equipment to detect potentially hazardous and unsafe conditions and take appropriate corrective action. Since maintenance personnel will be working in the work center, in the hangar, and on the line all of these areas should be included in the supervisor's inspection. He should check for explosion or inhalation hazards due to improper ventilation of working spaces, or careless handling of materials.

Spilled oil, grease, and chemicals should be wiped up promptly, and all rags used should be disposed of in covered metal containers.

Handtools should be in good shape, of the proper type, and used only for the purpose for which they were designed.

Fire hazards present another serious problem. "No Smoking" rules should be strictly enforced. Ground wires should be installed on every aircraft during maintenance to eliminate dangerous static electrical buildups.

GROUNDING

Grounding power tools and other equipment is a must and the supervisor is the man to see that this is done. It should not be necessary for a technician to be killed to once again emphasize the absolute necessity that portable power tools and other equipment be properly grounded. The importance of installing safety grounds to the cases of power tools or equipment must be stressed as a case of life or death—that is exactly what it is.

Another aspect of this problem, which deserves attention in a poor safety ground or one that is wired incorrectly. This may be more dangerous than no ground at all. A poor ground is dangerous because it does not offer full protection, yet it lulls the user into a false sense of security. The incorrectly wired ground is a hazard because transposing one of the line wires and the safety ground makes the shell of the tool "hot" the instant the plug is connected. Thus the unwary user is trapped unless, by pure chance, the safety ground is connected to the grounded side of the line on a single-phase grounded system. In this case, the user again goes blithely along using the tool until he encounters a receptacle which has its wires transposed.

The need for a safety ground is not hard to realize when you know that a few years ago statistics showed that, over a given period, 50 percent of the deaths in the Navy due to electric shock were caused by 115-volt electric potentials.

The reason for this high percentage is as follows: When the current through the body nears 100 milliamperes, death is almost certain. The body resistance, assuming dryskin, varies from about 1,000 to 500,000 ohms. With a 115-volt potential, a body resistance as low as 1,150 ohms can produce the necessary 100 milliamperes. With perspiration or water on the victim's hands, the body's resistance can go as low as about 300 ohms, resulting in a current of 384 milliamperes, which is normally lethal.

Portable power tools afford you an excellent opportunity to become part of a circuit. For example, if the motor winding is shorted to the case, the case will be at the same potential as the power applied. Then the path of least resistance may be you.

These facts caused SecNav to formulate the policy of grounding any exposed, noncurrent-carrying parts of electrically operated equipment powered from supply circuits of more than 50 volts. Several safety measures have been adopted to implement this policy.

In an effort to make certain that a safety ground is used, a requirement has been established for a 3-wire, color-coded cord with a polarized plug having a ground pin.

Since the polarized plug can be connected only to a mating receptacle, the user has no choice but to use the safety ground. (Adapters to change three-prong plugs to two-prong plugs are sometimes furnished, but they should never be used with power tools.) Supervisors should insure that the ground pin is not removed from the polarized plug. The color coding has been standardized to conform with the National Electric Code. All new tools which are properly connected use a green wire as the safety ground. The wire is attached to the metal case of the tool at one end and to the grounding pin in the connector at the other end. It normally carries no current, being used only when the tool insulation fails to bypass the current around the user to ground. Black and white leads are used as the current-carrying conductors: the white lead is the power ground of a single-phase system, and the black lead is hot.

The three-pin plugs and their receptacles have been designed to minimize the possibility of incorrect wiring. Looking at the end of a plug, you will notice that the pins are constructed so that they can be put into the receptacle in only one position. The ground pin is the longest and therefore will mate first and break last, insuring that the safety ground is connected at all times when power is applied to the circuit. In addition, the plugs are usually color coded. The three-prong plugs ordered under FSN 9N5935-280-2380 (Connector Plug, Electrical) have color-coded screws: The terminal screw on the safety ground prong is painted green; the neutral prong and screw are silver; and the terminal screw on the hot pin is brass. Thus, there should be no confusion when installing this type of plug.

One fact must be kept in mind when installing safety ground hardware. Although all portable power tools need this feature, some items of sensitive test equipment should not have their cases grounded. Grounding the case of some VTVM's, for instance, creates a possible ground loop which will support spurious signals, thereby hindering measurement accuracy.

If a cable requires replacing, be certain to replace it with the proper color-coded cord; and make sure that the green conductor is connected to the shell of the equipment. If the shell consists of more than one piece, make sure that all pieces are connected. Clean off any paint, and scrape the metal beneath it to make a clear, clean surface at the point of connection.

When it is necessary to use an extension cord, use only the type that has a grounded plug attached to one end and a grounded receptacle (suitable for connecting to the grounded tool plug) on the other.

If the tool or equipment is adequately grounded through a supporting bracket or bulkhead fastener, you need not use the ground cable. For your own protection, however, you should check the resistance to ground with a low-reading ohmmeter to be certain that the grounding is adequate (less than 0.1 ohm is acceptable). If the resistance indicates greater than 0.1 ohm, use either a separate ground strap or a three-wire cord; and check the ground connection to be certain of a good contact.

When installing a new cord or checking the tool for safety, examine the cord connections carefully. The cable wires should terminate in a standard crimped or solder type lug or connector; or, if stranded wire is used without a lug, the ends should be solder dipped. Form the wire into a loop (in the direction of the screw rotation) around the connecting screw; and make absolutely certain that no loose, fine strands of the flexible wire cord protrude to cause an accidental contact with the shell of the tool, receptacle, or plug.

High Voltage

All radars employ voltages which are dangerous and may be fatal if contacted. Practical safety precautions have been incorporated into every radar system; however, when the most basic rules of safety are ignored, the built-in protection becomes useless.

The following rules are basic and should be followed at all times by all personnel when working with or near high voltage circuits:

1. CONSIDER THE RESULT OF EACH ACT—There is absolutely no reason for an individual to take chances that will endanger his life or the lives of others.
2. KEEP AWAY FROM LIVE CIRCUITS—Do not change tubes or make adjustments inside the equipment with high voltages on.
3. DO NOT SERVICE ALONE—Always service equipment in the presence of another person capable of rendering assistance or first aid in an emergency.
4. DO NOT TAMPER WITH INTERLOCKS—Do not depend on interlocks for protection; always shut down equipment. Never remove, short-circuit, or tamper with interlocks except to repair the switch.
5. DO NOT GROUND YOURSELF—Make sure you are not grounded when adjusting equipment or using measuring equipment. Use only one hand when servicing live equipment.
6. Do not energize equipment if there is any evidence of water leakage; repair the leak and wipe up the water before energizing.

These rules, teamed with the idea that "voltage is not a respecter of persons" and that personal caution is your greatest safeguard, may prevent serious injury or even death.

ORGANIZATION AND ADMINISTRATION OF SAFETY PROGRAMS

In accordance with the Navy policy of conserving manpower and material, all naval activities are required to conduct effective and continuous accident prevention programs. The organization and the administration of a safety program are part of the requirements of the supervisor. The safety program must be in accordance with local instructions and based on information contained in the Navy safety precautions manuals. Work methods must be adopted which do not expose personnel unnecessarily to injury or occupational health hazards. Instructions in appropriate safety precautions are required to be given and disciplinary action taken in case of willful violations.

The work center safety program will generally involve three areas of attention—the posting of the most important safety precautions in appropriate places, the incorporation of safety lessons in the formal training program, and frequent checks for understanding during the day-to-day supervision of work.

Posted safety precautions are more effective if they may be easily compiled with; for example, a sign on the electronic test bench reads "ground high voltage of terminal before working on or near video indicator." Thus, a high voltage grounding probe should be installed in a convenient location.

Fixed posters and signs should be renewed frequently and not allowed to become rusty, faded, or covered with dust and dirt. General safety posters on bulletin boards and other places should be rotated often to stimulate interest. Appropriate safety posters may be obtained from the squadron or unit safety officer.

The formal safety training sessions should utilize films, books, visual aids, or any other suitable technical material. The men should be told more than just what or what not to do. Each safety subject should be explained in detail. The results of unsafe acts are usually the most dramatic and easiest remembered. Causes of accidents and contributing factors should be reviewed and analyzed. Many good ideas for accident prevention have been developed in training sessions.

An extensive series of lessons may be developed over a period of time as latent hazards are recognized, and this will aid in keeping the sessions interesting while avoiding too frequent repetition.

It may be well to mention the new man in the work center at this point. A separate safety indoctrination lesson which covers all the major hazards of the work center should be given the new man as soon as he reports for work. The supervisor with an effective safety program and an excellent work center safety record will take steps necessary to make sure that the new man is properly instructed, so as to prevent his being hurt.

In the third area of safety program administration—followup—the supervisor will do well to delegate authority to his subordinate petty officers to assist him in monitoring the program. Also included in the followup area is a responsibility of the work center supervisor to inquire as quickly and thoroughly as possible into the circumstances of accidents and reports of unsafe practices and take action or make recommendations.

Safety precautions are designed to cover usual conditions in naval activities. Commanding officers and others in authority are authorized to issue special precautions to their commands to cover local conditions and unusual circumstances. The work center supervisor will have to apply both sets of rules in the administration of his work center safety program.

Safety directives and precautions should be followed to the letter in their specific application. Should any occasion arise in which any doubt exists as to the application of a particular directive or precaution, the measures to be taken are those which will achieve maximum safety.

When new safety posters or precautions are posted, it is the responsibility of the work center supervisor to correctly interpret their application to his men. In this way he will be able to achieve a unity of thought and action in the observance of the required safety rule.

The organization's safety officer is available to assit in interpreting and suggesting ways of implementing various safety directives and precautions. Current directives require that a safety officer or safety engineer be assigned as head of the safety department, division, branch, or section, whichever is applicable, at all shore stations.

In most instances the hazards involved and the applicable precautions for a given type of work are the same whether the work is done afloat or ashore.

RADIOACTIVE TUBES

Radioactive material is used in quite a number of spark gap, TR, glow lamp, and cold cathode tubes.

In many cases the personnel charged with maintenance of equipment that contains radio active material are not aware that they are handling radioactive matter. Even if they do know, they are quite likely to take the matter too lightly.

Radioactive materials are intentionally added to the tubes to produce a continuous supply of ionized particles in the tubes. This assures that the tubes will always operate at the same voltage.

The radioactive material causes the tube to produce a continuous supply of ionized particles whether the tube is in storage, in transit, in the equipment, or in disposal containers. The general concept is that ionization occurs only when the keep-alive voltage is applied to the tube. This is fallacious, since the voltage only increases the rate of ionization; it does not affect the rate of decay of the radioactive material.

Radiological Hazards

Radioactive tubes, as normally used and stored aboard stations and ships, do not subject personnel to a dangerous amount of external radiation. As long as the radioactive tubes are not broken, the hazard is slight; but as soon as the tubes are broken, the hazard is increased because internal radiation is then possible by inhalation of radioactive materials. However, they should be handled very carefully to prevent breakage; also, it is recommended that technicians do not remove radioactive tubes from cartons until they are ready to be used. This will preclude the possiblity of the accumulation of unpacked tubes and help prevent accidental breakage.

Handling Broken Tubes

When a radioactive tube has been broken, it is advisable to observe the following rules, which apply when any material is contaminated by radioactivity:

1. Contact a medical officer.
2. Never permit any material contaminated by radioactivity to come in contact with any part of the body at any time. Wear rubber or plastic gloves at all times when it is necessary to handle radioactive wastes or broken radioactive parts.
3. Do not bring food or drink into the contaminated area or near any material that is radioactive.
4. Immediately after leaving the contaminated area, if you have handled radioactive material in any way, remove any clothing which might have become contaminated, and wash your hands and arms thoroughly with soap and water, especially before eating, drinking, or smoking.

Disposal

In order that the Atomic Energy Commission (AEC) shall have cognizance of all disposal areas, amounts deposited in each area, and disposal procedures, SecNav Instruction 4555.1 directs that all naval activities shall dispose of radioactive waste by transferring them to an activity licensed by the AEC or to an AEC land disposal site, except in certain cases which are described in the instruction.

In general, radioactive electron tubes should not be disposed of individually, but should be collected in a designated container with a tight-fitting lid and suitable markings until a reasonable quantity for disposal has been gathered.

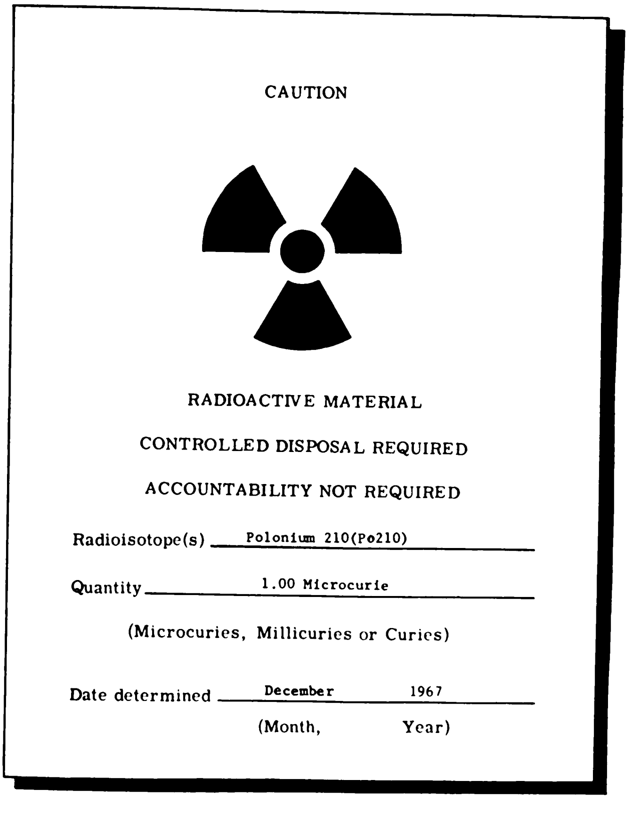
Tube and Container Markings

There are two types of marking or labeling of commodities and their containers, based on the level of activity of the radioisotope contained. Detailed information concerning the requirements of these markings and a list of the radioactive isotopes can be found in MIL-M-19590C(3).

Type I or type II markings must be placed on the radioactive source enclosure and on each surrounding container so that the presence of the radioactive material can be readily recognized and its location determined.

The color of both type I and type II symbols and the words "DANGER" and "CAUTION" will be magenta (purplish red) on a yellow background. Type I marking is as shown in figure 2-1. The words "controlled disposal required" mean that, as directed by SecNav Instruction 4555.1, naval activities must dispose of radioactive wastes through organizations licensed by AEC or through AEC land disposal sites whenever practicable. AEC controls the disposal locations and the amount of radioactive material deposited at each location in order to reduce potential hazards to the public.

Type II marking is shown in figure 2-2. The words "accountability required" means that each organization that uses and/or stocks radioactive tubes must keep records showing the receipt, transfer, export, and disposal of such items in accordance with existing instructions.



CAUTION

RADIOACTIVE MATERIAL

CONTROLLED DISPOSAL REQUIRED

ACCOUNTABILITY NOT REQUIRED

Radioisotope(s) Polonium 210(Po210)

Quantity 1.00 Microcurie

(Microcuries, Millicuries or Curies)

Date determined December 1967

(Month, Year)

AQ.3

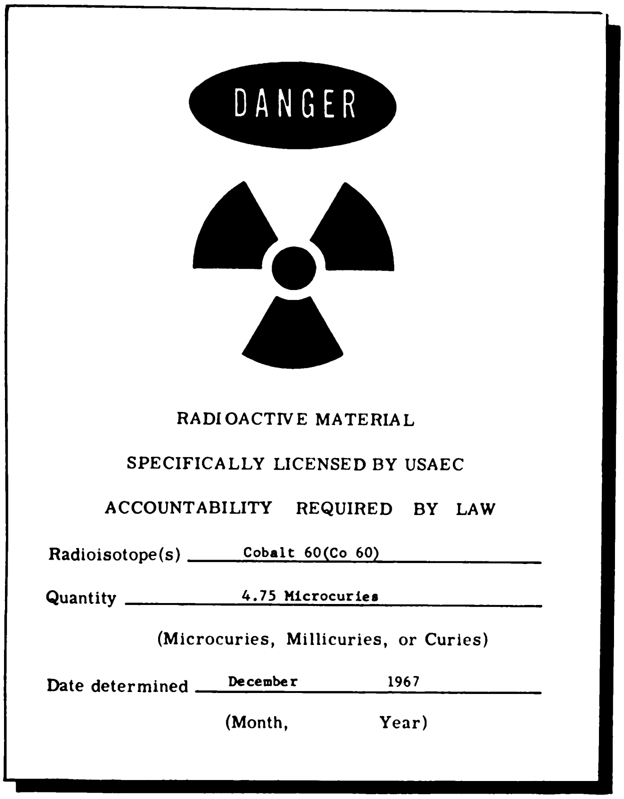
Figure 2-1.—Type I marking.

For special instructions concerning type II markings, refer to MIL-M-19590C(3).

CARE OF TOOLS AND TEST EQUIPMENT

One of the problems of the supervisor will be the care and proper use of tools and test equipment. It is sometimes difficult for some men to realize the need of a special effort in the care of the tools and other equipment necessary in the performance of their work. There are two main reasons for taking special care of these items: First, maintenance would be impossible without them; and second, they are costly and therefore are sometimes in limited supply.

The care of these items includes using them only for the purpose for which they were designed. A case in point is the use of the "Phillips" and "Reed and Prince" screwdrivers interchangeably. Most technicians have seen the tool and equipment damage caused by this malpractice. Other items such as soldering irons and guns, files, test leads, and small meters are among those which receive the most abuse.


DANGER

RADIOACTIVE MATERIAL

SPECIFICALLY LICENSED BY USAEC

ACCOUNTABILITY REQUIRED BY LAW

Radioisotope(s) Cobalt 60(Co 60)

Quantity 4.75 Microcuries

(Microcuries, Millicuries, or Curies)

Date determined December 1967

(Month, Year)

AQ.4

Figure 2-2.—Type II marking.

Test equipment is expensive and delicate; therefore, the care and proper use of this equipment will be of great concern to the supervisor. If the care of such equipment is not emphasized, it will soon deteriorate to a point where it is useless and, in fact, may even become dangerous. Meter leads must be properly stowed to prevent loss or damage; and if a cover is provided, it should be installed when the meter is not in use.

A system of stowing tools and other equipment must also be devised. The place for all tools should be marked, and everything not being used should be returned to its proper place. Toolboxes issued to Avionice personnel should contain a duplicate inventory list of tools issued with the box. The original should be kept in the work center files. Periodic inventory of these toolboxes is necessary since it is impossible to operate without an occasional loss or damage of tools. This inventory should be as frequent as possible to insure that no tools are left in an aircraft or equipment to cause foreign object damage (FOD).

JOB PRIORITY

Determining which jobs are to be performed first is one of the major responsibilities of the supervisor. This is an important phase of the maintenance operation because it will determine the use of facilities, men, material, and other equipment. The two major factors to consider when determining which job should come first are time and personnel required to complete the job.

Probably the most important single aid in estimating time and personnel requirements for aircraft maintenance tasks is the Periodic Maintenance Requirements Manual with its related cards, charts, and forms. Extensive time and motion studies of the various inspection requirements have been made and completion times are furnished in man-hours or man-minutes. These times also reflect routine maintenance, adjustment, and replacement if required in connection with the aircraft inspection. They are calculated on the basis that the most efficient number of men are continuously employed and that all necessary equipment, tools, and parts are immediately available. The supervisor must consider all these factors from the knowledge of his individual personnel, supply, and equipment situation, together with an accurate determination of the extent to which the maintenance task at hand exceeds the inspection requirements if he is to reliably predict the completion time. While this procedure may seem rather involved at first, the new supervisor will find that it is based on sound management principles and that, with experience, his ability to accurately predict time and personnel requirements will speedily improve.

SCHEDULING

If possible, the supervisor should avoid scheduling several jobs that may require identical tools and equipments to be performed at the same time. This often results in confusion and loss of time.

It is also important to schedule activities so that work is accomplished in the proper sequence. This is especially important if men are working on several different phases of the same job.

Time must be allowed in the schedule for assignment of future routine work. This may make it necessary to rearrange the present schedule to insure that special jobs will not interfere with the accomplishment of this work.

ASSIGNMENT OF PERSONNEL

Work assignments should be rotated so that each man will have an opportunity to develop his skills in all phases of the work. When assignments are rotated, the work becomes more interesting for the men. Another good reason for rotating work assignments is that if one highly skilled man performs all the work of a certain type, the supervisor and the work center would be at a great disadvantage in the event the man is transferred from the work center. Less experienced personnel should be assigned to work with him in order to become proficient in his particular skill. Also, in order to broaden his knowledge of his rate, the expert on one job should be rotated to other tasks when there is no immediate need for his particular skill.

Strikers should be assigned to various tasks so that they will acquire experience on all kinds of jobs. A special consideration for the assignment of strikers to jobs is that they should be assigned progressively to jobs of ascending levels of difficulty. A striker may be a useful assistant on a complicated job, but he may not understand what he is doing unless he has worked his way up from basic tasks.

CHECKING PROGRESS AND EVALUATING PROCEDURES

The assignment of work is only the beginning of job processing. The man in charge must know his men and have a fairly good idea of each man's skills and abilities. He must also be aware of each man's knowledge regarding the operation of equipment and the accomplishment of repair work.

The best way in which the supervisor can obtain this knowledge is to make frequent inspections and check the progress of work being performed. In that way he will have a good idea as to which jobs, or which men, will require the most supervision.

When checking the progress of work, the supervisor should make sure that the men are observing proper safety precautions in regard to themselves and the equipment they are operating. In addition, he should see that each man is using the proper tools, and note the quality of the work being performed.

In case of any doubt, he should check to see that his instructions are understood and that the work is being performed correctly. If necessary, he should provide additional instructions to give a better understanding of the job or to improve workmanship. By frequently talking to the men and answering their questions, the supervisor can prevent time and material waste, as could be the case if he were not available to give the correct details.

Complications may develop on some repairs which may require additional planning and revised repair procedures. By observing the progress of various jobs, and whether they are ahead or behind the planned schedule, the supervisor will be able to change the schedule in order to prevent any major work stoppage.

INSPECTING COMPLETED WORK

All work completed is subject to inspection by the crew supervisor and quality assurance inspector. The inspection is performed to aid in the reduction of human error and to insure that all material used was of the proper type and quantity. Quality assurance inspections are not used to replace the responsibility of the crew leader or supervisor but to enhance the reliability of a weapon or weapon system.

Generating quality in an organization necessitates a sincere interest on the part of commanding officers, plainly evidenced to the officers and men in their commands. Quality further requires that each officer and supervisor understand clearly how the accomplishment of a quality job contributes to the effective operation of the organization. Quality also requires that each worker understands not merely a set of specification limits, but also the intent and the need for these requirements.

The quality assurance organization is concerned with three functional areas—quality management, quality verification, and technical publications.

Quality verification assures that all materials processed and actions taken by all personnel meet prescribed quality requirements. Direct inspection of material and operations as they are performed is necessary on a continuing basis to give adequate assurance that all items processed and tasks completed meet the prescribed requirements. These quality assurance considerations (tests, inspection, etc.) are included in most weapon system Maintenance Requirements Card decks as well as most Maintenance Instructions Manuals, and Overhaul and Repair Manuals. Quality assurance verification steps are generally called for at various steps during repair progress in addition to verification of the final product.

Quality management is monitored by formulating, implementing, and auditing procedures, instructions, and operations to assure compliance with the policies stated or implied within the NAMP Manual. Quality assurance coordinates their efforts with those of the acitivity's data analysis group to provide information on maintenance practices and results based on facts gleaned from the various maintenance source documents and associated reports.

Inspectors

Personnel to be designated as inspectors should possess the following attributes:

1. Should be experienced and fully knowledgeable within his technical rating.
2. Should possess the ability to research, read, and interpret drawings, schematics, technical manuals, and directives.
3. Should be able to write with clarity and technical accuracy.
4. Should be observant, alert, and inquiring with a record of excellence and stability in the performance of his duties.
5. Should be able to work with others and possess the personal desire and motivation to develop a greater knowledge of his technical speciality.
6. Should be a senior in his paygrade and experienced.

Each man designated as an inspector should receive an indoctrination on quality assurance objectives, policies, and procedures as provided in OpNav Instruction 4790.2 (Series). The indoctrination requirement is directed toward developing an appreciation for the importance and necessity of an organized quality assurance effort on a continuing basis.

Training of Inspectors

Training of personnel involved in quality assurance and collateral duty inspection requires continuous training in weapon system familiarization, repair procedures, troubleshooting techniques, inspection, testing, and quality assurance considerations specifically applicable to their areas of maintenance.

Quality assurance representatives verify the adequacy and accuracy of inspections performed by the collateral duty inspectors of the work center. Collateral duty inspectors are permanently assigned to the work center and, in addition to other assigned duties, they are assigned to inspect work accomplished by other personnel within the work center. Both the representatives and the inspectors are designated in writing by the commanding officer. Only those personnel designated in writing are authorized to sign as inspectors on maintenance forms or to certify in any way that a component or equipment is ready for issue or use. A sample inspector designation form is provided in OpNav Instruction 4790.2. Copies of the form are kept in the quality assurance files and the division officer's files, with the original going in the man's service record.

PUBLICATIONS

The leading petty officer's duties require him to be familiar with all the publications associated with administration, supply, ordering, and maintenance of aviation electronic equipment pertaining to his assigned unit. He may be called on to complete forms, originate reports, originate requisitions, and perform many other duties consistent with the administration of an avionics division. Unless he has mastered the details of securing and maintaining publications, his value to his superiors and his ability to instruct the men under him is limited.

PUBLICATIONS INDEX

The Publications Index is made up of five parts, each of which serves a specific purpose. They are identified as follows:

Navy Stock List of Forms and Publications, NavSup Publication 2002, Section VIII, Parts C and D, Numerical Sequence List (also referred to as Numerical Index).

Equipment Applicability List (Volumes 1 through 7), NavAir 00-500A.

Aircraft Application List, NavAir 00-500B

Directives Application List, NavAir 00-500C.

Letter Type Technical Directives Equipment and Subject Application List, NavAir 00-500D.

A description of these lists and their uses is presented in the following paragraphs.

NavSup 2002, Section VIII, Parts C and D

Section VIII of this stock list contains Naval Air Systems Command (NavAirSysCom) publications. This section is made up of four parts—A, B, C, and D. Parts A and B pertain to ordnance publications. Part C is the numerical listing of manual type aeronautic technical publications, and Part D is the numerical listing of letter type publications. These two, Parts C and D, are referred to as the Numerical Sequence List of Numerical Index of the Naval Aeronautic Publications Index.

Part C of this stock list contains a numerical listing, by code number, of available aeronautic technical manual type publications. In addition to the code number, the publication title, security classification, and date of issue or date of latest revision are given. The instructions for using the stock list include an explanation of the code number system used to identify the manuals by subject group. Also included in this section is information on ordering and methods of procurement of publications. Another section of the stock list is devoted to a cross-reference index of Air Force, NavShips, and NavOrd publication numbers to the NavWeps publication numbers.

Part D of the stock list contains a listing of the letter type technical directives. These are grouped by subject matter and, in addition to the same information that is listed for manuals in part C, an effective date is included if applicable.

All titles of publications listed in these stock lists are unclassified unless marked "1" (Confidential) in the column headed SC (security classification). However, this marking is not classification authority. The bimonthly supplement contains information pertaining to changes in classification action on a when occuring basis. The supplement, in itself, is authority for making classification changes on NavAir publications.

NavAir 00-500A

Naval Aeronautic Publications Index, NavAir 00-500A, Equipment Applicability List, is a cross-reference index listing of Naval Air Systems Command (NavAirSysCom) publications of aircraft components and related equipment according to model, type, or part number.

Since this index contains several thousand entries, one volume would be very cumbersome to use. For this reason, this index is divided into several volumes. At the time of this writing, there are seven volumes. Each of the first six volumes contains 400 pages, and volume 7 contains the remaining entries.

With the exception of several small sections in the first part of volume 1, the Equipment Applicability List is one continuous index of model, type, or part numbers in alphanumeric sequence.

In addition to an introduction, which explains the heading at the top of each page, the other sections in the first part of volume 1 pertain primarily to manuals for aircraft, weapons systems, and aircraft engines. Therefore, the publication numbers are listed according to aircraft, aircraft engine, and weapons system designation.

The Equipment Applicability List should be used when attempting to determine what publications are available on a particular item of equipment when the manufacturer and part number of the item are known.

NavAir 00-500B

The Aircraft Application List, NavAir 00-500B, contains a listing of all manuals grouped according to their application to an aircraft. This part of the index does not contain listings of any letter type publications, and all manuals are listed by publication code number only.

A list of basic numbering categories is provided in the front of the book. This list may be used in determining the general type of equipment covered in a publication. For determining the specific item of equipment covered by a publication and the title of the publication, reference should be made to Part C of Section VIII in NavSup Publication 2002.

The aircraft application List is especially handy for determining what manuals are available for a particular model of aircraft. Included under each model is a complete listing of applicable manuals. This listing includes all allowance lists, aircraft manuals, engine manuals, accessories manuals, etc., pertaining to that particular model of aircraft.

NavAir 00-500C

The Directives Application List by Aircraft Configuration, NavAir 00-500C, contains a listing of the active Naval Air Systems Command letter type technical directives with respect to their applicability to aircraft. The lists in this volume are arranged first by aircraft series, second by aircraft configuration, and third by Airframe/Aircraft Bulletin and/or Change numbers. (NOTE: Configuration refers to modifications made to a basic aircraft model. For instance, A-4A, A-4B, TA-4F, etc., are all different configurations of the A-4 aircraft model.)

NavAir 00-500D

The Equipment and Subject Applicability List, NavAir 00-500D, is a relatively new addition to the Naval Aeronautic Publications Index. It contains a cross-reference index listing of Naval Air Systems Command letter type technical directives. It serves the same purpose for letter technical directives as the Equipment Applicability List, NavAir 00-500A, does for technical manuals, However, since NavAir 00-500D lists only those model/type part numbers for which technical directives have been issued, it is much smaller than NavAir 00-500A. The complete list is contained in one volume but is divided into two parts. Part A is the Equipment Index and Part B is the Subject Index.

Part A contains a listing of all Naval Air Systems Command letter type technical directives on aircraft components and related equipment by model/type part number. Each number is listed in alphanumeric sequence within its cognizant equipment series. At the present time, Part A is divided into nine series. The Avionics Series is of most interest to the AT personnel.

Part B of NavAir 00-500D contains a listing of active Naval Air Systems Command letter type directives by subject. This part of the list pertains primarily to Airframe Bulletins and Changes.

Each List in the Naval Aeronautic Publications Index is updated at regular intervals by the issuance of a new list. In addition, some of these lists are kept current by the periodic issuance of supplements between issues of the basic list. The dates and intervals of the issuance of new lists and supplements have changed from time to time in the past.

At the time of this writing, the Numerical Index (Parts C and D of NavSup Publications 2002) is issued annually in September. Supplements are issued bimonthly between each basic issue. The Equipment Applicability List, NavAir 00-500A, is issued annually in November. This list is kept current by the issuance of quarterly supplements between each basic issue. The Aircraft Application List, NavAir 00-500B, is issued in March and September, and the Directives Application List by Aircraft Configuration, NavAir 00-500C, is issued in January and July of each year. Supplements are not issued for these lists.

The Equipment and Subject Application List, NavAir 00-500D, is issued in May and November of each year, and supplements are issued as the information is developed.

Supplements list all aeronautic publications distributed during the previous period, and those publications that have been superseded, canceled, or revised. Supplements are cumulative; that is, all material from the preceding supplement is incorporated in the latest supplement. Therefore, at any given time, not more than one supplement is in effect for any list. Naturally, the reissue of a basic list cancels the outstanding supplement.

Supplements for the Numerical Index (Parts C and D of Section VIII of NavSup Publication 2002) are identified by the word "supplement" printed near the upper right-hand corner of the cover. Supplements to the NavAir 00-500A Series publications are identified by the word "supplement" printed in the middle of the cover page.

USE OF PUBLICATIONS

As a first class or chief, your responsibilities in connection with installing, adjusting, maintaining, and testing electronic equipment will be much greater than they were when you were a lower rated petty officer. You will be required to have quick and accurate answers to many questions. Since there is a wide variety of complex equipment, you cannot expect to have a ready answer to all questions. However, you will become familiar with the published materials that contain the answers, and by so doing you will be able to take positive action.

Maintenance Instructions Manual

A Maintenance Instructions Manual is distributed for each type of aircraft. Recent manuals are issued with the sections as separate volumes to facilitate the use of the manual by the different work centers. The sections concerning electric and electronic systems maintenance and wiring data are of prime interest to the AT.

Location of components and instructions for removal and installation are included in the manual. The wiring diagrams, power distribution charts, and drawings showing the location and connection of fuses and circuit breakers are valuable to the technician while troubleshooting in the aircraft.

Information on electronic equipment maintenance is also included. The amount of this information or the depth of maintenance discussed will vary from one manual to another and also between equipments within a given manual. Included in some manuals for organizational maintenance are operational and functional checks, trouble isolation charts, and adjustment charts. The intermediate maintenance section may contain information for bench checks, troubleshooting, disassembly, repair and parts replacement, and assembly instructions. If special support equipment is needed to accomplish the maintenance described, a section on use and maintenance of this support equipment may be found in the volume on electronic maintenance. These manuals, when used in conjunction with the Service Instruction Manual for the electronic equipment, furnish the technician with information needed to properly maintain the equipment.

Operation and Service Instruction Manuals

The Naval Air Systems Command procures Operation and Service Instruction Manuals for various avionics equipments. The Operation and Service Instruction Manuals may be issued as one combined manual or as separate manuals. In some cases, where the equipment is installed in only one aircraft, the Maintenance Instructions Manual for that aircraft will contain the information normally found in the Operation and Service Instruction Manual.

Aviation Electronics Technician 3 & 2, NavPers 10317-D, lists the subject content of each section of this manual. The discussion in this course will be limited to a few of the items contained in the manual.

PERFORMANCE SPECIFICATIONS.—As a senior AT, your responsibilities for inspecting the work of others will increase. The Operation and Service Instruction Manual contains charts or sections on standards the equipment should meet if it is to be considered as performing satisfactorily. The use of this information to determine the quality of your own work or the work of some other AT is recommended. The preflight checks given in the manual usually give only an indication of overall system operation and do not indicate how much above minimum standards each section is operating. There are some equipments that utilize line testers for this check; line testers quite frequently are of the GO, NO-GO type. This is the most basic of the performance standards the equipment must meet.

The portion of the manual that gives the performance standards for the individual sections of the equipment is titled "Minimum Performance Checks" or "Specifications." These standards are work center procedures used to check the individual sections of the equipment against the acceptable performance levels. In addition to listing the minimum acceptable performance levels, this section gives procedures for setting up the equipment for test, the test equipment to use, and the adjustments required to bring the equipment up to standard.

The specific checks given will vary with the type of equipment—communications, navigation, or radar. Some checks of the type found in this category are as follows:

1. Receiver sensitivity.
2. Transmitter power output.
3. Signal-to-noise ratio.

4. Bearing or range accuracy check.
5. Receiver recovery time.
6. Frequency tolerance.

Where the equipment fails to meet minimum performance standards, a malfunction is indicated. Trouble analysis charts and alinement procedures are included in the manual to assist the technician in locating and correcting the malfunction.

ADJUSTMENTS.—The Operation and Service Instruction Manual contains charts and instructions for adjusting the equipment. One of these charts will be found in the organizational maintenance section of the manual. The information given will concern minor repairs and adjustments.

The adjustments given in the field maintenance section are more extensive than those in the section on organizational maintenance. Normally included in this section are the complete alinement procedures for each section of the equipment. The instructions include the step by step procedures and give the test equipment setup required.

SPECIAL TOOLS.—The Operational and Service Instruction Manual furnishes a list of special tools required for maintaining the specific equipment. The technician should check the applicable allowance list to determine whether the tools are available to his unit as organizational property or if it will be necessary to procure them on custody from the supporting activity.

TECHNICAL LIBRARY

The aeronautical technical library serves two important functions: First, it provides a central source of up-to-date information for the use of all technical personnel in the current performance of their work; and second, it is an excellent source of reference information to facilitate personnel training and individual improvement. To perform these functions properly, the technical library must contain at least one copy of all publications affecting assigned aircraft, ordnance, and related equipment, in accordance with the maintenance level responsibility involved. Initial outfitting allowances are sufficient to establish the technical library. However, additional copies of selected publications must be ordered for ready availability and use at the working levels.

Management of the technical library is a function of the QA Division (AIMD responsible for the Avionics technical library aboard carriers). This function includes the determination of technical manuals required to support the maintenance organization, receipt, and distribution control of these manuals, as well as the responsibility for insuring manual updating throughout the maintenance organization. These responsibilities also apply throughout the entire activity when the Maintenance Department has cognizance of all aeronautical technical manuals for the activity.

Modern technology is constantly changing. Today's best practices may be modified, totally revised, or made obsolete tomorrow. This is not always a planned or intended condition, but it must be accepted and dealt with. Such a condition requires that prompt action be taken to change and revise material related to the technical information and data used by maintenance and operations personnel. The urgency of this action depends upon the type of information involved and the frequency of reference to the affected directives or manuals. However, technical data change and revision material, once it has been screened and routed, should not be allowed to accumulate at any point. Procedures must be established throughout the organization to insure prompt action in revising and updating all technical information and data. It is mandatory that those responsible for the management of the technical library also be responsible for insuring that technical change and revision material reaches all department levels having copies of the affected directives or publications. TPL (Technical Publication Location Cards) should be maintained in the QA Division to indicate the location of all publications within the department. Proper use of this card will provide effective technical manual management within the central and dispersed libraries. Change Entry Certification form (OpNav Form 5070-12) should be used to insure that all change and revision material is entered in the directives and manuals that are not physically maintained in the technical library.

PROCUREMENT OF DATA

The AT supervisor must continue an effective program of review of the publications and other technical data required by his department, division, branch, or crew. Publications and directives are provided to aid the supervisor and worker in meeting commands commitments. As new data are published, it must be made available to the worker. This is a responsibility of the supervisor, who must know the procedures for requisitioning and how to be placed on the automatic distribution list.

Mailing List Request For Aeronautical Technical Publications (NavAir Form 5605/3)

Future issues of aeronautical publications and technical directives that are needed on a continuing basis can be received automatically by submitting two copies of NavAir Form 5605/3 to Naval Air Technical Services Facility (NATSF) in Philadelphia, Pa. When new publications or directives are published, NATSF automatically makes distribution to activities on the Standard Navy Distribution List. (This list is prepared from the NavAir Forms 5605/3 received). NavAir Form 5605/3 is a four-part form. Each part is used to request addition to the mailing list for the types of publications listed on each part.

Submission of this form is normally accomplished by the Quality Assurance Division (AIMD aboard carriers for AT's) for all divisions of a maintenance department in a squadron.

Part 1.—Part 1 of NavAir Form 5605/3 is used when an activity has a continuing requirement for Allowance Lists, Indexes, and General Series Technical Manuals/Directives.

Part 2.—Part 2 of NavAir Form 5605/3 is used when an activity has a continuing requirement for Allowance Lists, Airframe Manuals/ Technical Directives, and Powerplant Manuals/ Technical Directives.

Part 3.—Part 3 of NavAir Form 5605/3 is used when an activity has a continuing requirement for Component Manuals.

Part 4.—Part 4 of NavAir Form 5605/3 is used when an activity has a continuing requirement for Ship Installation Manuals/Technical Directives.

Procurement of Existing Data

Manuals that are current cannot be requested on NavAir Form 5605/3. Data that is already distributed is requested in different ways, depending on the type of data and the originator.

NAVAIRSYSCOM MANUALS.— NavAirSysCom manual type publications are ordered by preparing and submitting the Single Line Item Requisitioning System Document (DD Form 1348 or DD Form 1348M) in accordance with the Military Standard Requisitioning and Issue Procedure (MILSTRIP) as outlined in NavSup Pub 437. These manuals can be received by submitting a DD 1348 to the supply point listed on the inside cover of NavSup Manual 2002. NavSup Publication 2002, Section VIII, Part C, contains a listing of all NavAirSysCom Manual publications and their stock numbers.

NAVAIRSYSCOM LETTER TYPE TECHNICAL DIRECTIVES.—NavAirSysCom letter type technical directives listed in NavSup Pub 2002, Section VIII, Part D, may be requested on DD Form 1149. The request form should be forwarded to Naval Publications Form Center (NPFC) for all technical directives listed except for those denoted with an asterisk. Those identified by an asterisk may be procured by submitting a letter of justification to Naval Air Technical Service Facility (NATSF) in Philadelphia, Pa.

FILING CORRESPONDENCE

The Department of the Navy Standard Subject Identification Code, SecNav Instruction 5210.11 (Series) provides a single, standard subject scheme. This classification system is used for classifying Navy and Marine Corps documents by subject throughout the Department of the Navy. SecNav Instruction 5210.11 contains a list of standard subject classification numbers and a list of name-title subject classification codes. Except at activities with an exceptionally large volume of correspondence, files normally are established by subject classification numbers. However, files may be established by name-title codes or a combination of both. These classification numbers/codes and their use are discussed in the following paragraphs.

Directives Issuance System

The directives issuance system provides a uniform plan for issuing and maintaining directives. Directives consist of written matter which prescribes or establishes policy, organization methods, or procedure; require action; or contain information essential to the effective administration or operation of activities concerned.

Instructions are directives of a continuing nature and remain in effect until subsequently canceled. Notices are directives of a one-time nature or directives which are applicable for a brief period of time (usually 6 months of less). Each notice contains a provision for cancellation, on which a specific data is stated for record purposes.

For the purpose of identification and filing, standard subject classification numbers classify Navy correspondence and directives under 13 major series groups. These major series groups are further subdivided by use of the last 3 digits in the major series. The 13 major series groups consist of the following:

1000 Series—Military Personnel
2000 Series—Communications.
3000 Series—Operations and Readiness.
4000 Series—Logistics.
5000 Series—General Administration and Management.
6000 Series—Medicine and Dentistry.
7000 Series—Financial Management.
8000 Series—Ordnance Material.
9000 Series—Ships Design and Ships Material.
10000 Series—General Material.
11000 Series—Facilities and Activities Ashore.
12000 Series—Civilian Personnel.
13000 Series—Aeronautical Material.

MISCELLANEOUS PUBLICATIONS

There are a great number of technical publications, other than the maintenance and service instructions, that the AT will find useful in performing his job. This section lists and describes briefly a few of these publications. By including this type of publication in the technical library, the supervisor will be providing information that should increase the efficiency of the work center.

Handbook of Installation Practices for Aircraft Electrical and Electronic Wiring, NA 01-1A-505

This manual was written for the following purposes:

1. To bring together under one cover the recommended practices and techniques to be used for installing, repairing, and maintaining aircraft electric wiring.
2. To standardize these techniques and methods so that electrical/electronic installations are performed in a uniform manner.
3. To indoctrinate all personnel with the importance of good workmanship.
4. To point up the failures which may result from poor workmanship.
5. To promote safety by pointing out and prohibiting unsafe practices.

The information contained in the manual represents the best current knowledge and practice in the avionics field. It has been compiled with the cooperation and assistance of leading airframe manufacturers, airline operators, and military overhaul and repair bases. Many of the illustrations have been provided by the manufactures of electrical accessories used in aircraft.

The following topics are covered:

1. Wire and cable preparation.
2. General purpose connectors.
3. RF connectors and cabling.
4. Solderless terminations and splicings.
5. Thermocouple wire soldering and installation.
6. Bonding and grounding.
7. Bus bar preparation.
8. Conduit fabrication.
9. Installation of bus bars, conduit, junction boxes, protective devices, and terminal strips.
10. Electrical wiring installation.
11. Lacing and tying.
12. Safety wiring.
13. Emergency repairs.

This manual can be of much assistance to the leading petty officers because it contains the answers to many questions. Also, it is an excellent teaching aid in carrying out your on-the-job training duties.

Reduction of Radio Interference in Aircraft, NA 16-1-521

The purpose of this manual is to present information which will serve as a guide to the aviation industry and to naval aircraft maintenance activities for reduction of radio interference in naval aircraft. It may be used as a guide to enable you to determine the type of interference, to locate its source, and to provide a means for its elimination or suppression.

The information is presented under the following headings:

1. Purpose.
2. Types and effects of radio interference.
3. Sources of radio interference.
4. Interference coupling.
5. Basic installation planning for radio interference control.
6. Radio interference reduction components; their selection, application, and installation.
7. Bonds and bonding.
8. Shields and shielding.
9. Testing for radio interference.
10. Maintenance aspects of radio interference.

Handbook of Test Methods and Practices, NavShips 0967-000-0130

This manual is written to meet the technician's need for convenient reference on the fundamentals of testing electronic equipment. The wide scope of information, covering both theory and practice, makes the manual equally valuable for the beginning technician and the technician who has much experience. The manual has been reviewed by technicians in work centers and in schools in order to make it as effective as possible. It is presented in five sections as follows:

Section 1, Testing in General, discusses the importance and functional divisions of testing, along with some associated testing information, and explains the need for various types of measurements and tests.

Section 2, Test Equipment and Measurements, provides the technician with a background in test equipment circuit theory. With this background he will be better able to select the most suitable test equipment for a particular job and to interpret correctly the data received. In addition he will be qualified in the use of both general and specialized test equipment. All of these abilities are important requirements for efficient performance testing and troubleshooting.

Section 3, Testing Techniques and Practices, covers in detail the specific procedures used in testing equipments. In this section the selection of test points, the correct interpretation of tests, and the selection of suitable test equipments are stressed as important requirements for efficient testing.

Section 4, Waveform Interpretation, discusses the interpretation of the common voltage and current waveforms as observed on an oscilloscope or other test equipment. Information regarding complex waveforms and phase development given in this section illustrates and explains the normal waveform.

Section 5, Antenna and Transmission Line Measurements, discusses methods used in performing quantitative tests on transmission systems.

Section 6, Systems Testing, contains information on electronic systems ranging from monitoring normally operating systems to system troubleshooting.

Periodic Maintenance Requirements Manual

This manual contains the planned scheduled maintenance requirements for the aircraft concerned and is the controlling document for the planning and accomplishment of the related work tasks through all levels of maintenance.

The maintenance requirements contained in this manual specify the equipments to be inspected or examined and the required conditions. It does not contain instructions for repair, adjustments, or troubleshooting, as this type of information is found in the Maintenance Instructions Manual for the particular aircraft.

The planned maintenance requirements prescribed by the Periodic Maintenance Requirements Manual are considered to be the minimum necessary under any conditions to assure timely discovery and corrections of defects. The listed designated calendar intervals are the maximum authorized based on aircraft class and planned Navy-wide utilization. Due to varying operational requirements, climatic or environmental conditions, squadron commanders may increase the scope or frequency of material inspection or examination as required to properly and safely carry out assigned missions.

Part I of this manual contains sections on maintenance management, definitions, preflight, daily and calendar inspection procedures, and references.

Part II contains fleet maintenance requirement data for daily, calendar, special, and preflight inspections.

Part III includes the requirements for progressive aircraft rework. The first section of Part III contains instructions on squadron responsibility and rework activity responsibility. The rest of the sections are a listing of the systems of the aircraft.

Part IV contains the component removal and/or replacement schedule. The replacement time intervals are indicated in the operating hours, calendar time, or Progressive Aircraft Rework (PAR) periods as appropriate. Components are arranged according to systems.

Part V is a listing of the components by part number and nomenclature which require accessory card entry into the appropriate logbook.

Periodic Maintenance Information Cards

When published, these Periodic Maintenance Information Cards will replace the Periodic Maintenance Requirements Manual. These information cards contain much of the same information previously found in the Periodic Maintenance Requirements Manual. The cards are used in the same manner as the Periodic Maintenance Requirements Manual but have eliminated the duplication of information on the information cards and the Maintenance Requirement Cards (MRC's). The information cards will also insure that both the MRC deck and the information cards are updated at the same time as is not always the case with the Periodic Maintenance Requirements Manual and the MRC deck.

Department of the Navy Safety Precautions for Shore Activities NavMat P-5100

The purpose of this manual is to present the safety precautions applicable to Navy shore activities including shore (field) activities of the operating forces and fleet schools. The safety precautions given in this manual are of necessity basic and general in nature and are not inclusive of all conceivable operations and functions involved in the great variety of shore activities. In many instances references are made to other publications for detailed safety precautions applicable to specific operations.

The senior AT should become very familiar with the contents of this manual. It is the responsibility of supervisory personnel to see that safety precautions are strictly adhered to. Continuous cooperation and vigilance of all personnel are needed to see that all operating procedures and work methods do not unnecessarily expose personnel to injury or property to loss or damage.

Handbook Preferred Circuits
NA 16-1-519

This publication is designed primarily for engineering standardization. It does, however, contain information of interest to the AT. Another publication in this category is the Guide Manual of Cooling Methods for Electronic Equipment, NavShips 0900-027-9010.

Semiconductor Device Replacement Guide, NA 16-1-530

This publication contains replacement technical, and mechanical information on all semiconductor devices listed in the Navy Supply System.

Security of Classified Publications

Security is one of the chief responsibilities confronting the Avionics Division. Although security is the duty and responsibility of all hands, security rests very heavily upon electronics supervisors because of the classification of the equipments, systems, and publications with which AT's work.

Department of the Navy Security Manual for Classified Information
OpNavInst 5510-1 (Series)

The objective of the orders and instructions contained in this publication is to establish a coordinated policy for the maintenance of the security of all matter classified in the interest of national defense. The United States Navy Regulations, the Espionage Act, and Atomic Energy Act, executive orders, and other legally established directives form the basis for this publication. These regulations do not restrict the mature judgment of individuals in the proper application of initiative, and local commands may issue additional security instructions as necessary to meet local situations. However, this manual contains detailed procedures and outlines basic responsibilities of the security system. Reference to this manual will provide methods of implementation of the security system for most encountered circumstances. The senior AT should be familiar with this publication.

SECURITY

Commanding officers are responsible for establishing security orientation, education, and training programs for all personnel assigned. OpNav Instruction 5510.1 (Series), chapter 3, provides the necessary minimum requirements for implementing these programs.

The central aim of the security education program is to make all personnel "security-minded." To achieve this, a continuing training program must be in use at all levels of the command, with emphasis by the senior petty officers to their subordinates.

Effective security also requires that the handling of classified materials be managed in an efficient manner. Good management practices are important in obtaining effective security control. If security needs are to be met, constant attention must be given to the way in which classified material is handled. The guide for handling and control of classified material is OpNav Instruction 5510.49 (Series).

SECURITY ORIENTATION, EDUCATION AND TRAINING PROGRAM

The security orientation, education, and training program of each command must include all personnel entrusted with classified information regardless of their position, rank, or grade. The program must be designed to include the following:

1. Familiarize all personnel with the security requirements with which they have to comply for proper performance of their duties and assignments.
2. Remind all echelons of command of their responsibility for assuring that classified defense information is effectively and economically safeguarded.
3. Insure willing, conscientious compliance with security regulations, procedures and practices.
4. Remind all echelons of command of their responsibilities in the classification management program to include classification, upgrading, downgrading and declassification processes as set forth in OpNav Instruction 5510.1 (Series).
5. Advise all personnel who have access to classified information of the hazards of its disclosure to any person not authorized to receive it and of their responsibility for exercising personal vigilance for its protection.
6. Inform all personnel of the techniques and devices employed by foreign intelligence activities in attempting to obtain U.S. classified defense information and of their responsibility for reporting such attempts.
7. The attention of all personnel must be directed to the disciplinary action (Article 0815 of OpNav Instruction 5510.1 (Series) that may result from violation of security regulations.

Personnel Indoctrination

Persons being assigned to duties requiring access to classified information, prior to being granted access, must be indoctrinated on the security aspects and responsibilities of their assignment. The indoctrination must include the strict prohibition against discussing classified information over the telephone. This is especially important because of the fact that many calls are transmitted through microwave transmitters and can be easily recorded and analyzed. The types of situations to be avoided when talking on the telephone are:

1. Allowing classified information to slip into conversations through carelessness.
2. Disclosure of classified information in order to expedite the completion of a "rush project."
3. Use of codes, "double talk" or attempt to talk around classified information. It should be noted that private codes and "talking around" classified matters presents no real protection against the abilities of a trained analyst.

As part of the indoctrination program, personnel must be instructed to report promptly any of the following types of information:

1. Attempts by representatives or citizens of communist controlled countries to cultivate friendships or to place personnel under obligation.
2. Attempts by representatives or citizens of foreign governments to:
    a. Cultivate a friendship to the extent of placing them under obligation, which they would not normally be able to reciprocate, or by money payments or bribery to obtain information of intelligence value.
    b. Obtain information of intelligence value through observation, collection of documents, or by personal contact.
    c. Coerce personnel by blackmail; by threats against or promises of assistance to relatives living under their control, especially those in a communist country.

d. Appeal to personnel on a racial, nationalistic, or ideological basis.

e. Exploit personnel who may be disaffected or in personal difficulties.

f. Intimidate, harass, entrap, discredit, search, spy on, or recruit for intelligence purposes personnel traveling in communist countries.

g. Induce personnel to defect or to induce those who have fled from communist countries to redefect.

3. Attempts by Department of the Navy personnel to provide unauthorized services, information, or documents to anyone believed to be in contact with a foreign intelligence service.

4. Attempts by persons living in communist countries to obtain information of intelligence value from personnel by correspondence (including "Pen Pal" correspondence), questionnaires, "ham radio" activity, naval cachets (request to service postal covers), or other forms of communications.

Senior petty officers to whom information of the above nature becomes known must:

1. Instruct the reporting individual to take no action to exploit, apprehend, restrict, or stimulate further contact until appropriate guidance or instructions are received.
2. Report full details expeditiously to the commanding officer who should report his findings to the nearest Naval Investigative Service Officer.

Briefings and Debriefings

Periodic briefings must be held by all commands for personnel having access to classified information. These briefings must include special emphasis on the subjects discussed in Article 0305 of OpNav Instruction 5510.1 (Series).

In addition to the periodic security briefings, the former article also contains information on foreign travel briefings and potential hostage briefings.

Article 0306 of the Security Manual provides the necessary information for debriefing personnel who have had access to classified information and the security access has been terminated for any reason.

CLASSIFICATION

Information that will aid the senior petty officer in safe-guarding classified material can be found in Articles 0405, 0406, 0423, 0424, 0426, 0432, and 0443 of the Security Manual. The contents of these articles should be familiar to all senior petty officers.

Regrading and Declassification

Overclassification of information and retention of information in classified status when it no longer requires such protection cause unnecessary delay and expense in handling and transmission, overburden stowage facilities and depreciate the classification system. Under such circumstances, security control is virtually impossible to enforce and to maintain. Therefore, downgrading and declassification must be accomplished whenever possible.

A mandatory, continuing program based on a time schedule for automatically downgrading, and in most cases automatically declassifying, documents originated within the Department of Defense has been established by the Secretary of Defense. Determination of specific dates or passage of events that will provide early downgrading or declassification should be made as a matter of practice. When this is not possible, classified material must be categorized into one of the four groups described in the following paragraphs for automatic downgrading and declassification of classified information. Downgrading and declassification groups are as follows:

Group-1 Material

Material in this group is completely excluded from the automatic downgrading and declassification provisions either because it has been removed from such provision or because it contains information not subject to the classification jurisdiction of the Executive Branch of the U.S. Government.

Group-1 material may be downgraded or declassified only by the originating authority, or by an official higher in the same chain of command.

Group-2 Material

Material in this group is exempt from automatic downgrading and automatic declassification because it contains extremely sensitive information originally classified TOP SECRET or SECRET.

The authority for designating material as Group 2 is granted only to those officials empowered to exercise original TOP SECRET classification authority. This authority may not be delegated and shall be exercised only when required in the interest of national security. It is intended that the number of Group 2 documents be kept to an absolute minimum.

Group-2 material may be downgraded or declassified only by the originating authority or by an official higher in the same chain of command.

Group-3 Material

Material in this group warrants some degree of classification for an indefinite period. Group-3 material is exempt from automatic declassification. Unless the originator specifies a shorter interval, they shall be downgraded automatically as follows:

(a) TOP SECRET material will be downgraded to SECRET 12 years from date it was created and to CONFIDENTIAL 24 years from date it was created, and will remain CONFIDENTIAL.

(b) SECRET material will be downgraded to CONFIDENTIAL in 12 years, and will remain CONFIDENTIAL.

(c) CONFIDENTIAL material will remain classified.

Group-3 material may be declassified only by the originating authority or by an official higher in the same chain of command.

Group-4 Material

Group-4 material includes all classified material which does not qualify, or is not assigned to, one of the first three Groups.

Group-4 material is automatically downgraded and declassified as follows:

(a) TOP SECRET material will be downgraded to:

(1) SECRET 3 years from date it was created.

(2) CONFIDENTIAL 6 years from date it was created; and

(3) Declassified 12 years from the date it was created.

(b) SECRET material will be downgraded to:

(1) CONFIDENTIAL 3 years from the date it was created: and

(2) Declassified 12 years from the date it was created.

(c) CONFIDENTIAL material will be automatically declassified 12 years from the date it was created.

Each original and derivative classifying authority is similarly authorized to reclassify and declassify official information previously classified by virtue of his position. Such authority includes changing the downgrading and declassification group to which information may be initially assigned.

Custodians are authorized to reclassify and declassify classified information in accordance with the downgrading and declassification markings affixed to classified information. In the case of classified information received via a receipt or log book signature system, the classified material control officer must be notified whenever a document has been remarked in accordance with this paragraph.

Higher authority in the chain of command or higher authority having primary cognizance over the subject matter involved shall correct an erroneous classification which has been assigned by a subordinate, or downgrade or declassify information when such action is deemed appropriate.

When the interests of two or more commands are involved in the reclassification of information, coordination between such commands is required.

KEYS AND COMBINATIONS

It is essential that combinations or keys be accessible only to those personnel whose official duties demand access to the container involved. The combination to a security container should be changed whenever one of the following conditions occurs:

1. When the combination lock is received.
2. When a person having knowledge of the combination leaves the organizational unit.
3. When there is reason to believe the combination has been compromised.
4. When the lock has not been changed in a 12-month period.

PERSONNEL SECURITY CLEARANCES

Any person having access to classified matter must have a security clearance. NEVER assume the security clearance of anyone regardless of rank or rating or previous activities. Always demand valid proof of entitlement to classified information. Limit access to classified information, and to the files, to a ''need to know'' basis (information necessary for the performance of the individual's duties). On the other hand, remember that avionics personnel, due to the nature of their ratings and the continual need for updating their education on the latest avionics system, should be properly cleared and have access to material relevant to the duties of their ratings. Leading petty officers should take the lead in establishing the right balance in this area.

PLANNING FOR ADVANCED BASE OR FORWARD AREA OPERATIONS

A Chief Aviation Electronics Technician must be able to prepare for advanced base or forward area operations by estimating aircraft spare parts and supplies, equipment, and manpower requirements for aviation electronic repair. In determining requirements for forward area or advanced base operations, it is necessary to consider the following:

1. Mission.
2. Environment.
3. Operating factors.
4. The availability of existing facilities.

A knowledge of the material and manpower requirements as listed in the Advanced Base Initial Outfitting Lists of Functional Components will be very helpful. The functional component is one of more than 300 standardized units of the system which the Navy has developed to enable it to build and operate its advanced bases in the least possible time and with a minimum expenditure planning and logistic effort.

A functional component is a list of the requirements for the performance of a specific task at an advanced base, and consists of a carefully balanced combination of material, equipment, and/or personnel.

Each functional component is classified according to its primary function into 1 of 11 major groups, including aviation. Each major grouping is identified by letter designation and title; the functional component contained in each are identified by a combination letter, number, and title designation. The major group letter for aviation is H.

H components are designed to provide for maintenance, support, and operation of aircraft in an advanced area under combat conditions, and may be combined with other functional components to form several types of air stations.

Information and data are given in the abridged and the detailed outfitting lists for functional components.

It should be apparent to the AT that the advanced base requirements may not be exactly as they appear in the Advanced Base Initial Outfitting Lists. In order to use these lists as guides, it will be necessary in most cases to alter or tailor them to fit the individual needs of the unit about to deploy.

Other necessary repair parts, supplies, and equipment may be determined from the outfitting and allowance lists for the aircraft or other weapon system to be supported.

It is quite likely that the avionics CPO will be required to advise the personnel office in making assignments of individuals to advanced base or forward area operating units. It would seem logical that the number of Electronic Technicians assigned to deploy be in the same ratio as the percentage of supported aircraft scheduled to deploy. This may be true if the proposed flight hours per aircraft of the detachment exactly equaled the planned utilization of the remaining aircraft and if there are no significant environmental problems to be overcome. The list of personnel assigned to deploy should represent a cross section of the skill levels available unless special maintenance factors indicate otherwise. The selection of personnel should be made as objectively as possible so that the deployed unit may function efficiently without working a hardship on the home group.

CHAPTER 3

AVIATION SUPPLY

A Chief or First Class Technician, especially if in a supervisory billet, will find himself increasingly involved in the details of supporting the man on the job. One of these detail areas is in the field of aviation supply.

Aviation supply personnel are vital member's of the aircraft maintenance team; and the technician as well as the other aviation maintenance ratings must work in close harmony with them if successful teamwork is to be achieved. The team must work so that a flow of parts is maintained from the manufacturer to the man on the job—quite possibly a technician doing repair work on the other side of the world. A correct concept of supply's relationship to the entire organization is essential in the supervision of aircraft maintenance functions.

ORGANIZATION AND FUNCTION OF NAVAL SUPPLY

Prior to the establishment of the Aviation Supply Office (ASO), aircraft spares were bought by the naval bureaus, naval air stations, and the Naval Aircraft Factory as they were needed. This system, though efficient enough before World War II when aircraft component parts were few, was too loosely organized for the great expansion of the Navy's aircraft program that followed the fall of France in 1940.

ASO was established in 1941 under the technical control of BuAer and the management control of BuSandA. The function of ASO was the procurement, custody, and issuance of aeronautical spare parts and technical material.

Today, ASO supports approximately 8,500 aircraft. The aircraft have changed; the methods of controlling their spare-part support have changed. But ASO's mission today is the same as it was during World War II—to insure that the Navy's aircraft have the right parts, in the right quantities, in the right place, and at the right time. ASO is now under the technical control of the Naval Air Systems Command and the management control of the Naval Supply Systems Command.

RESPONSIBILITIES OF THE NAVAL MATERIAL COMMAND

The Chief of Naval Material (CNM) is responsible for providing the material support needs of the operating forces for equipment, weapons or weapons systems, materials, facilities, and supporting services. He also formulates and effectuates policies and methods of procurement, contrating, production of materials, and of procurement and contracting services throughout the Navy. CNM heads six principal subordinate commands. Two of these commands are concerned with aviation supply and are discussed below. (See fig. 3-1.)

Naval Supply Systems Command (NavSup)

NavSup is responsible for supply management policies and methods and provides ASO with the following:

1. Command guidance and supply system policy.
2. Operating funds for civilian salaries, office equipment and supplies, and travel.
3. Navy Stock Funds for financing procurement of consumable aeronautical spares.

Naval Air Systems Command (NavAir)

NavAir is responsible for Navy and Marine Corps aircraft and airborne weapons systems and other aviation-related equipment, and the systems integration of aircraft weapon systems. NavAir provides ASO with the following:

1. Technical guidance.
2. Weapons systems program data.
3. Funds for the procurement of aeronautical repairables.

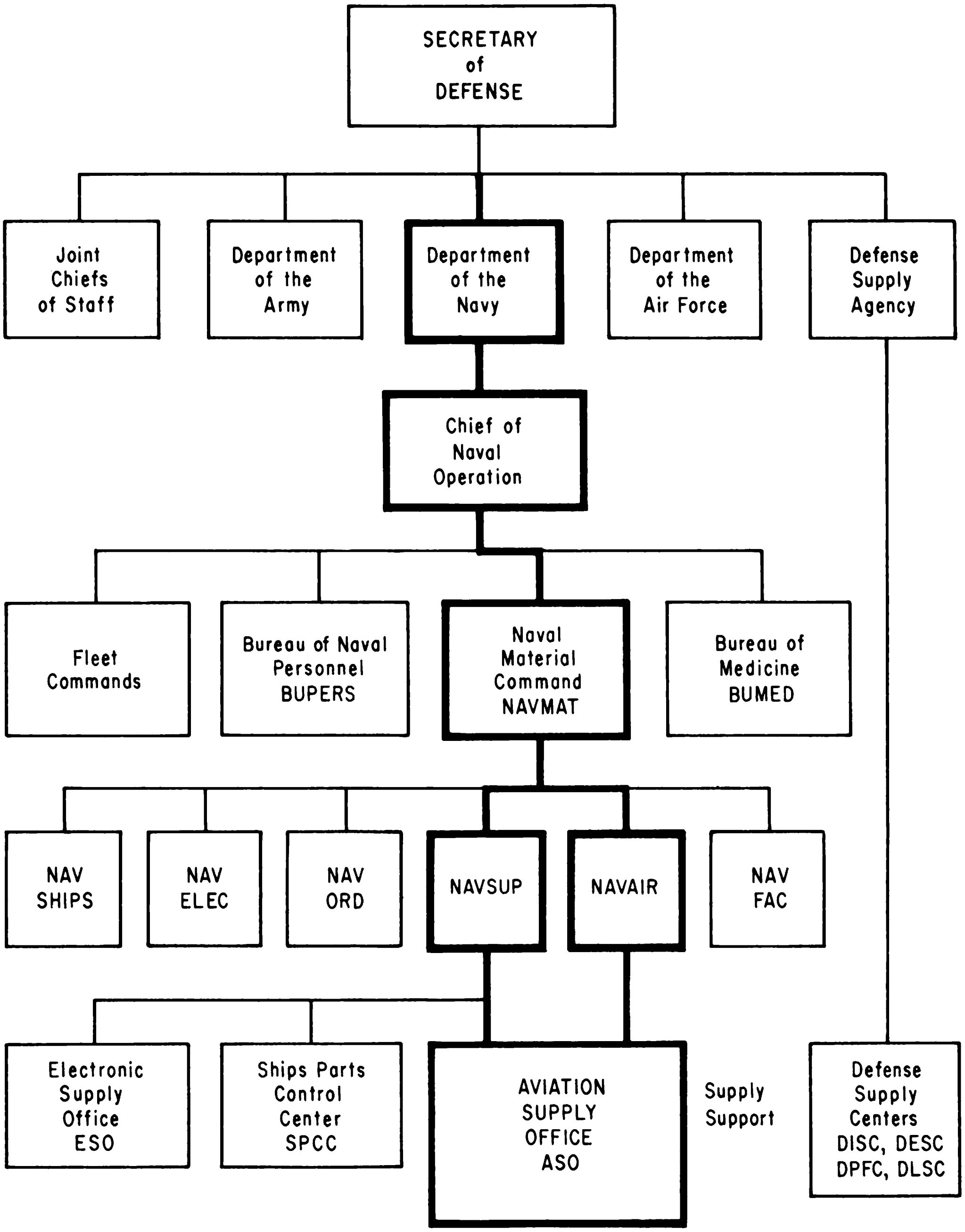


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Figure 3-1.—ASO's relationship within the Department of Defense.

Aviation Supply Office (ASO)

Picture a giant mail order business with warehouses in principal cities, with distribution points located close to consumers, and doing business on a worldwide basis. ASO—the nerve center of the aviation supply system—is that kind of business. ASO provides supply support to naval aircraft and aeronautical support equipment worldwide. Categories of material include the following:

1. Aeronautical spares.
2. Photographic equipment and repair parts.
3. Meteorological supplies.
4. Catapult and arresting gear parts.

As a Navy Inventory Control Point (ICP), ASO performs all the basic functions of an inventory manager. Some of the functions are outlined as follows:

1. Requirements determination including:
    a. How much and when to buy.
    b. Distribution/redistribution.
    c. Repair.
    d. Offers to other services.
    e. Budget.
    f. Stratification.
    g. Disposal.
2. Purchase.
3. Technical and cataloging services.

APPROPRIATIONS

At one time or another, almost everyone has had the frustrating experience of not being able to draw from supply some item that he thought necessary to have immediately; the usual reason given being, "We don't have any money left." It takes only a short time to realize that the Navy does not operate with unlimited funds. This section and the following section, titled "Funding," are presented to further an understanding of the system whereby funds are made available at the user activity level for operating expenses.

The main money pool of the government is the General Fund of the Treasury. Funds come into the General Fund from such sources as income taxes, excise taxes, import-export taxes, etc. The only way for money to be expended from the General Fund is by congressional action, which has to be approved by the President. A bill passed by Congress which authorizes the expenditure of funds from the General Fund is called an appropriation.

An estimate of the amount of money required for the operation of the Defense Department during a given fiscal year is prepared by Department of Defense fiscal experts well in advance of the beginning of the fiscal year. The Congress studies the proposed budget in the light of world affairs, the current domestic economy, and such other considerations as they see fit, then acts upon it. They may increase the amount requested, decrease it, or pass it as submitted. After presidential action is completed, the money is made available to the Department of Defense to be spent during a specified year. This is known as an "annual" or "1-year" appropriation.

Congress and the President may also approve "no-year" appropriations for special projects such as large construction over an unspecified length of time. Another form of appropriation is the "multiple-year" appropriation for projects which will be completed in a predictable length of time. An example of this type of appropriation might be the money appropriated to cover the expenses of the NROTC college programs for the next 4 years.

The appropriation by which the AT is most affected is the current year appropriation. After the appropriation or expenditure authorization is received in the Department of Defense, it is prorated among the services as a percentage of their previously submitted budget estimates. The Navy's share is prorated among the various bureaus and commands in essentially the same manner; that is, as a percentage of their estimated requirements for the coming fiscal year. The money to be spent for naval aviation is made available to CNO. Here, part of the money is allocated to ASO for the purchase of aircraft spare parts in quantities which past usage data has indicated will probably be sufficient for the coming year. These spare parts are furnished to the operating activities at no cost, since their usage has been anticipated and the items paid for in advance. The account from which money was spent to buy these items is known as the Appropriation Purchase Account (APA). Material received in the user activities from this account is know as APA material.

Another part of the CNO funds is made available to the operating activities in the form of operating funds.

FUNDING

All aviation activities responsible for operating aircraft are provided funds for certain operational and organizational maintenance expenses under the O&MN (Operations and Maintenance, Navy) appropriation subhead 1911 or in the case of the Naval Air Reserve, O&MN appropriation subhead 1912. These funds are intended to provide for all fundable supplies in the operation of aircraft and for fundable materials used in the organizational maintenance of assigned aircraft. It is intended that funds provided to intermediate maintenance levels will perform the assigned maintenance within their scope, and such funds are not to be used to procure this service from other naval activities. The funds are for fundable supplies only (labor is performed by military personnel and not a fundable charge). Housekeeping, administrative, and other similar expenses are to be provided by the supporting ship or station and are not chargeable to these funds.

Maintenance Funds

Funds used for the operation and maintenance of naval aircraft and related equipment are defined as maintenance funds. Maintenance managers must familiarize themselves with these funds and their respective purposes, since responsibility must be commensurate with funding.

Aircraft Operating Funds

Aircraft operating funds finance the following:

1. Aviation fuels and lubricants (POL) consumed in aircraft.
2. Flight clothing and operational equipment authorized in the NA0035QH-2 allowance list, with the exception of exchangeable aeronautical equipment, such as lifevests, rafts, parachutes, etc. (These exceptions are financed by Aviation Maintenance funds.)
3. Squadron administrative (office) consumable supplies.
4. Aerial film used in aircraft.
5. Flight deck/safety shoes used by squadron personnel in the readiness, launch, and recovery of aircraft.
6. Initial issue of unit identification marks for newly reporting personnel.
7. Liquid and breathing oxygen used during flight operations by both the aircraft system and pilot.
8. Forms and publications (Cog symbol III) and the printing and reproduction thereof.
9. All reimbursable maintenance material procured when located at other than the parent supporting ship and/or station, including APA material procured from other Government agencies or commercial concerns, by aircraft on extended flights. (This does not include aircraft maintenance funds, which are furnished by the Operations Maintenance Division of the station at which the aircraft has landed.)
10. Liquid oxygen.

Air Staff Administration and Operations Funds

Air Staff Administration and Operations funds finance the following:

1. Administrative office supplies for daily operations.
2. Office equipment and accessories not classified as investment items.
3. Rental of office machines on a contract basis.
4. Special incentive awards for staff or aviation units. These awards should contribute towards motivation and a high degree of morale and be purchased on a minimum basis.
5. Special flag office accessory items.

Aviation Outfitting Funds

Aviation outfitting funds are made available to finance the initial outfitting of all allowance list and Table of Basic Allowances (TBA) equipment issued to Navy squadrons and deployable aircraft, as organizational property and the replacement of authorized organizational property with nonconsumable material accountability and recoverability codes.

1. Initial outfitting is defined as:
    a. Initial issue of any item or organizational property to a squadron or unit during an interval from the time of commissioning, terminating 6 months after the date of commissioning.
    b. Initial issue of allowance list and TBA items during an interval from date of allowance list change, terminating 6 months after the date of the allowance list change.
    c. Initial issue of increased allowed quantities during an interval from the date of authorization for the increased quantity, terminating 6 months after the date of the authorization.
2. Aviation outfitting funds do not support Section C equipment, Section P material and

equipment, or any additional required maintenance support tools and equipment not specifically designated as organizational property.

Fleet Outfitting Equipment Funds

Fleet outfitting equipment funds finance the following:

1. Initial issue of special fleet outfittings and reoutfitting of equipment (organizational property) as authorized and directed by the type commander through the administrative commanders.
2. Replacement of the above items if authorized by the type commander.

Temporary Additional Duty Travel Funds

Temporary Additional duty (TAD) travel funds are provided to finance temporary additional duty travel expenses for personnel attached to type commander aircraft squadrons and units. Expenses financed included the following:

1. Returnable school quotas for aviation unit personnel.
2. Aviation crew rotation.
3. Inspection, logistic support, and other administrative travel by fleet aviation unit personnel.
4. Deployments and emergency leave.
5. Emergency quarters while on extended flight.
6. Storage of household effects while on TAD.

Aviation Maintenance Funds

Aviation maintenance funds finance the cost of NSA (Navy Stock Account), DSA (Defense Supply Agency), GSA (General Services Administration), and open-purchase materials and supplies consumed in the performance of aviation organizational and intermediate maintenance, including the costs of the following:

1. Technical repair parts, common hardware, lubricants, cleaning agents, cutting compounds, metals, etc., incorporated into or expended in the performance of aviation maintenance of aircraft, aircraft engines, aeronautical components and subassemblies, GSE, and consumable IMRL items.
2. Fuels and lubricants (POL) used in the test, check, and runup of engine or components.
3. Rag or red towel service and cleaning.
4. Preexpended, consumable maintenance material.
5. Replacement of expendable/consumable allowance list items (Material Accountability and Recoverability Codes B and C), including IMRL items.

Fleet Funding

Appropriations for operation and maintenance, Navy, are allocated to each fleet commander for financing supplies and equipage requirements and tender availability. Fleet commanders are responsible for the administration of and accounting for funds allocated to them and must maintain official accounting records and submit reports as required. Fleet commanders issue an allotment to each type commander to finance supplies and equipage requirements and tender availabilities of all ships and flags under his command. (Under the resources management system, this grant is called the expense operating budget.)

A type commander grants authority to ships and commands under his control to cite his allotment for materials and for certain services. This "obligational authority" is referred to as operational target or OPTAR.

OPTAR Funds

OPTAR funds are provided each command by the type commander and are controlled by the commanding officer with the supply officer maintaining an accurate record of command expenditures.

Senior AT's aboard ship are concerned with OPTAR in keeping supply records on a divisional level. Normally aviation squadron AT's are not required to keep records of OPTAR expenditures; this service is performed by the material control division for the entire squadron.

Chapter 5 of Military Requirements for Petty Officer 1 & C, NavPers 10057-C, (Supply), contains additional information on supply and funding.

MATERIAL IDENTIFICATION

As part of the aviation maintenance team, the technician will be working closely with the aviation storekeepers in keeping aircraft in an "up" status. In order to obtain replacement parts as rapidly as possible, the technician must know how to determine the source of supply of different items. For example, many hours may be wasted trying to find that the item is to be manufactured within the activity. Also, it is important to know the correct stock number and cognizance symbols used to requisition items from supply.

The cataloging system developed by the Department of Defense is such that it identifies with one name and stock number any item of supply that is carried in any or all government agencies. In the procurement of material it is normally necessary to identify your material requirement in the medium understandable to the supply system.

FEDERAL STOCK NUMBERS

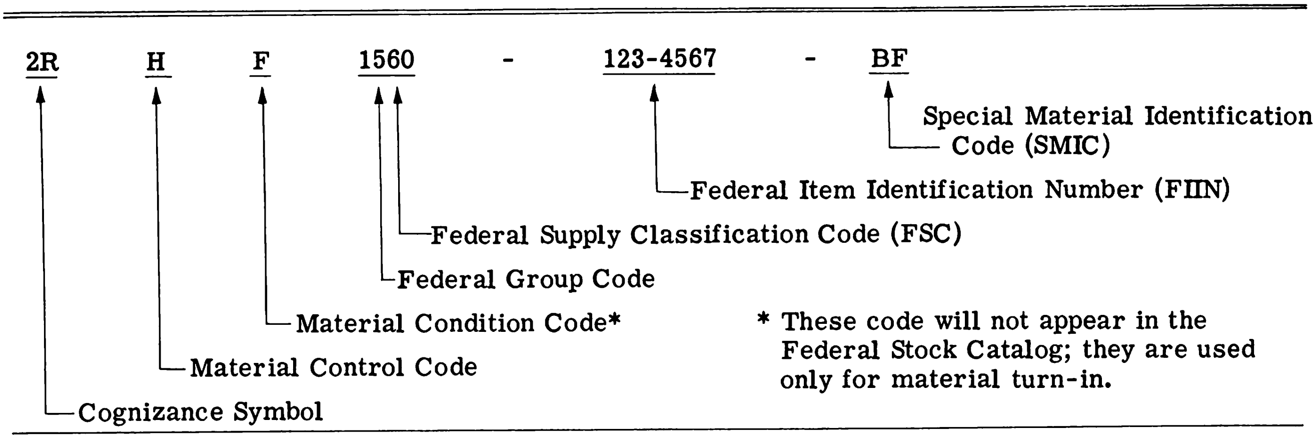
Prior to 1952 each of the services had its own numbering system for identifying, cataloging, stocking, and issuing items of military supply. It was not unheard of that one service would be negotiating on the open market for an item that was held in surplus by another service under its own stock number. This confusion resulted in the passage in 1952 of the Defense Cataloging Standardization Act.

The implementation of this Act has resulted in a reduction of item duplication between the services by providing for one Federal Stock Number (FSN) for each item, regardless of the use of the item or the using activity.

Coded Federal Stock Number

The federal stock number consists of an 11-digit number. The Aviation Supply Office uses federal stock numbers with prefixes composed of one, two, or three symbols, and suffixes composed of two characters which may be all letters or a combination of letters and numbers. When the prefixes and suffixes are used, the federal stock number becomes a coded federal stock number. A coded federal stock number and its breakdown is shown in table 3-1.

Table 3-1.—Breakdown of a coded Federal stock number.


2R
H
F
1560
-
123-4567
-
BF
Special Material Identification Code (SMIC)
Federal Item Identification Number (FIIN)
Federal Supply Classification Code (FSC)
Federal Group Code
Material Condition Code*
Material Control Code
Cognizance Symbol
* These code will not appear in the Federal Stock Catalog; they are used only for material turn-in.

If a 1-symbol prefix is used, it designates the command or office having control or cognizance of a particular item. Listed below are some of the more common cognizance symbols, together with the type material controlled and the name of the cognizant command or office.

SYMBOL	COGNIZANT ACTIVITY	MATERIAL CONTROLLED
2R	Aviation Supply Office	Aeronautical material
2V	Naval Air Systems Command	Major aeronautical equipment
1N	Electronic Supply Office	Electronics assemblies and repair parts
1W	Fuel Supply Office	Fuels, lubes, and gases

SYMBOL	COGNIZANT ACTIVITY	MATERIAL CONTROLLED
1I	Navy Supply Depot, Philadelphia	Forms
0I	Navy Supply Depot, Philadelphia	Publications

Many variations of coded stock numbers will be encountered in field maintenance work. These variations indicate material management responsibilities for the item; flag certain items as recoverable, consumable, high value, etc.; and identify the condition of the material if it is not ready for issue. Some of the more common codes that a technician is likely to encounter include the following:

RH—a recoverable aeronautical component of high value.

2RHF—a recoverable aeronautical component of high value that is not ready for issue.

Because the variety of codes is so extensive and the trend to single service management of items has caused so many changes in recent years, a list of codes that might be prefixed or suffixed to a stock number would not be appropriate for this manual. The primary things to keep in mind are that the basic stock number, consisting of three groups of numerals, identifies the item from a technical point of view and that the other codes identify material management characteristics.

With the advent of the single manager concept many items formally carried in the individual Navy Stock Lists are cataloged in the Federal Supply Catalog For General Supplies. The complete catalog consists of many sections and is arranged by federal supply classification class.

IDENTIFICATION DATA SOURCES

There may be times when a part or some technical material is needed and the stock number is unknown. At other times some material may be on hand and its identity is not positively known. A knowledge of the several methods by which material may be identified is very helpful in speeding the completion of a maintenance task. There are many ways in which material may be identified. Certain data may be available which does not identify an item but may lead to positive identification. An aircraft part has a part number. The part number may be looked up in the IPB and identified by nomenclature and often by the stock number. If the stock number is not furnished in the IPB, it may be found by referring to the Cross-Reference Section C0006 of the Navy Stock List of ASO.

Some equipments have attached nameplates which provide such information as the manufacturer's name, make or model number, serial number, size, voltage, phase, etc. Identification data taken from the nameplate of the old part can be very helpful in procuring a replacement.

When only the description of the item is known, the best source for identification is the descriptive sections of the various Navy Stock Lists.

Various publications used in identifying material are described in the following paragraphs.

Illustrated Parts Breakdown (IPB)

The IPB continues to be the most important source for obtaining information necessary to order specific aircraft and equipment parts. Properly used, the IPB will provide reference information necessary to identify a part number to the specific model aircraft and in some cases provide interchangeability data that can be utilized when the prime item requested is not in stock.

IPB's are compiled by the manufacturer for each aircraft model in naval use. IPB's, as discussed here, encompass IPB's for aircraft, IPB's for aircraft engines, and IPB's for individual accessories and equipments.

Although slight variations in format exist among the various IPB's, each normally includes the following major sections:

I. TABLE OF CONTENTS—This section shows the breakdown of the catalog into sections and furnishes a cross-reference between the various assemblies and figures where they are illustrated. The section also cross-references assemblies and pages where they are broken down into subassemblies and parts.

II. INTRODUCTION—This section includes general information and instructions for using the publication. Because variations between IPB's do exist this section should be referred to prior to using an IPB with which your are not thoroughly familiar.

III. GROUP ASSEMBLY PARTS LIST—This section is the main text of the publication. It consists of a series of illustrations and parts lists in which all parts of the aircraft/engine/equipment are shown in assembly breakdown order. The illustrations and parts lists are keyed to each other by means of figure and index numbers. Each assembly included in the parts lists is followed immediately by its component parts properly indented to show their relationship to the assembly. The group assembly parts list is subdivided into groups such as wing group, tail group, and fuselage.

IV. NUMERICAL INDEX—This sections lists all parts in alphanumerical order, and each part is cross-referenced to the figure and index number where it is illustrated. This list also shows the official source code of each part listed in the applicable IPB.

The MASTER LOCATOR INDEX replaces the numerical index for some aircraft IPB volumes. The master locator index is used to locate the manual in which a part number will appear when only the part number is known. The part numbers are listed in alphanumerical order. The manual number appearing in the manual No. column refers to the last dash number of the NavAir manual number. For example: If the number shown in the manual No. column of the A-6 master locator index is 8, complete information on the part will be found in IPB volume, NA 01-85-ADA-4-8. The master locator index, unlike the numerical index, does not always provide source, maintenance, and recoverability information.

If a failed part is one that was installed as a result of a technical directive, the part number may not appear in the IPB. The index manual for the IPB volumes will include a list of directives which have been incorporated into the IPB's. For information on parts where the directive has not been incorporated, the directive may provide the necessary information for ordering a replacement item.

The REFERENCE DESIGNATOR INDEX, normally the last section of the IPB, is a listing of reference designators (C104, R103, etc.) used on the electrical and electronic wiring diagrams. The reference designator index will aid in the location of parts where only the reference designation number is known.

Aeronautical Allowance Lists

This title is inclusive of publications identified as Allowance Lists (except advanced base lists), Initial Outfitting Lists, and Tables, of Basic Allowances.

Aeronautical Allowance Lists are prepared by the Naval Air Systems Command or by activities as designated and directed by this command. These lists contain the following:

1. The equipment and material (both consumable and nonconsumable) necessary to outfit and maintain units of the aeronautical organization in a condition of material readiness.
2. Substantially all items used with sufficient frequency to justify their issuance to all activities maintaining aircraft or equipment for which the lists are designed.
3. Information concerning stock number, nomenclature, interchangeability, and supersedures.
4. A set of detailed instructions for the application and utilization of the publication.
5. A table of logistic data showing the total weight and cube of all material contained in the list.

In the final analysis, Aeronautical Allowance Lists are lists of equipment and material determined from known or estimated requirements as necessary to place and maintain aeronautical activities in a condition of material readiness.

Aeronautical Allowance Lists are reissued in accordance with reissue cycles established by the Naval Air Systems Command, or sooner, if required. Interim to reissues, the lists are maintained current by letters and by the issuance of Change Pages and Change Bulletins. Change Bulletins, which are official publications, are issued by ASO on a monthly basis, are numbered in consecutive numerical sequence within each calendar year, and are distributed to holders of allowance lists. For checkoff purposes, a Change Bulletin Index is also published by ASO semiannually and distributed in the same manner as the Change Bulletins.

Allowance lists indicate the range and quantities of support equipment considered necessary for maintenance support of assigned and/or supported aircraft. Generally, these items are in-use items required for daily or continual use, such as handtools and avionics test equipment.

Initial outfitting lists (IOL's) are publications which indicate the range and quantities of maintenance spare parts considered necessary to support various aeronautical articles. This material is provided to vessels or activities and is firm only at the time of initial outfitting. Increases and decreases in both range and/or quantities of material are based upon the experience (demand history) of each activity concerned. Each series list is designed to support an aircraft, electronic equipment, or some other aeronautical article. The allowances of material are established for various articles for a 90-day period. All items capable of replacement by a maintenance activity are not listed, but rather, only those that are expected to be used at least once in a 90-day period.

Publications listing equipment and material required for performance of specific functions are known as Tables of Basic Allowance. They contain both shop equipment and common supporting spare parts. They cover allowances of tools and equipment required for use by such activities as Fleet Marine Force squadrons and guided missile activities.

Initial Outfitting Lists and Allowance Lists are identified by the publication number NA 00-35Q series, while Tables of Basic Allowance are identified by the publication number NA 00-35T series. Those allowance lists of primary interest are listed in the following paragraphs:

Section "A" Initial Outfitting List (NA 00-35QA-1)—Lists standard aeronautical and Navy stock account material (nuts, bolts, hose, paint) common to the designated aircraft classes.

Section "B" Initial Outfitting List (NA 00-35QB)—Series lists peculiar maintenance parts (airframe, engine, accessories) required for support of specific aircraft models. (Includes lists for certain target aircraft and guided missiles.)

Section "BR" Initial Outfitting List (NA 00-35QBR)—Series lists peculiar maintenance parts (airframe, engine, accessories, electronics) required for support of concerned target aircraft model, drone helicopter, or guided missile. (Prepared in lieu of separate Section "B" for airframe, engine, accessories, and Section "R" lists for electronic parts due to limited installation of electronic equipment.)

Section "G" Allowance List (NavAir 00-35QG)—Series lists general handtools, consumable support equipment items, and installed shop equipment required for maintenance support of aircraft.

Section "R" Initial Outfitting List (NA 00-35QR-6)—Lists aeronautical electronic accessories common to designated aircraft classes.

Section "R" Initial Outfitting List (NA 0035QR-30)—Series lists peculiar repair parts, spare components, assemblies, and subassemblies required for maintenance of appropriate aeronautical electronic equipments.

Section "T" Allowance List (NA 00-35QT)—Series lists special maintenance support equipment required for intermediate and organizational levels of maintenance of airframes, powerplants, accessories, avionics equipment, and/or aircraft model to which the list applies.

Section "X" Initial Outfitting Allowances List (NA 00-35QX-30)—Series lists peculiar parts, spare components, assemblies, and subassemblies required for maintenance of the armament, fire control, instrument, or electrical system to which the list applies.

Section "Z" Initial Outfitting List (NA 00-35QZ-30)—Series lists peculiar repair parts for mobile electric powerplants, precision measuring equipment, peculiar and common GSE.

Tables of Basic Allowances (NA 00-35T)—Series (T-37-1, T-37-2, T-37A, T-38-2, and T-41), lists equipment and material required by activities to which the list applies for performance of assigned mission. Lists presently in effect relate to the following activities:

T-37-1	Fleet Marine Force Aviation Activities (Not having aircraft assigned).
T-37-2	Fleet Marine Force Aviation Units.
T-37A	Fleet Marine Force Aviation Units (Supply Officers' material and equipment).
T-38-2	Navy Tactical Control Squadrons.
T-41	DASH Weapons System Operational and Maintenance Activities.

Weapon Equipment Lists

Equipment parts lists catalog material according to the type of aircraft or equipment it is designed for rather than what it is. ASO is in the process of developing a Weapon Equipment List (WEL) for each aircraft type. For example, WEL 0076 and WEL 0086 contain lists of repairable assemblies, supporting repair parts, attaching parts, loose equipment, and accessories for the A-7A and the A-4 (Series) aircraft, respectively.

A WEL contains a cross reference listing from the manufacturers part number to the federal stock number. The WEL is a comprehensive multivolume publication containing all the management data necessary for identification and procurement of items for the aircraft type covered. It also contains a list of allowance lists, major avionics equipment, and technical manuals applicable to the aircraft and a section containing explanations of the various codes and information on how to use the publication.

Cross Reference Lists

The term "cross reference list" is a general term normally relating to cross referencing between reference numbers/ manufacturer's part numbers, and federal stock numbers. Most catalogs published by the Navy or the Defense Supply Agency have a cross reference section listing part numbers and stock numbers of items contained therein.

A master cross reference list (MCRL) is the term applied to a publication which accumulates and consolidates the information from all the separate cross reference lists. The Defense Logistics Services Center (Defense Supply Agency) publishes an MCRL for the Navy which is distribured by the Fleet Material Support Office (FMSO). Also, ASO publishes an MCRL entitled "ASO Cross Reference for Naval Aviation Interest Items—Part Number to Federal Stock Number." (ASO section C0006). The FMSO MCRL is a more comprehensive publication (approximately 24 volumes plus a multivolume supplement) and contains information of interest to all elements of the Navy. ASO's MCRL, along with C0006A (variation code supplement), is tailored to aviation requirements. It would be the preferred MCRL for aviation supply support activites. Other specialized MCRLs published by ASO include:

1. Section C0017, Master Cross Reference of Parts Kits—identifies repairable assemblies to their repair parts kits.
2. Section C0018, Model Code Cross Reference List—identifies ASO's model codes, which appear in various ASO catalogs, to the FSN's of the repairable assemblies to which they apply.
3. Section C0020, TSMC/WSMC to SMIC conversion guide of Navy aviation materials—for converting FSN with old Technical Supply Management Codes (TSMC) and Weapons System Management Codes (WSMC) to the new FSN with a Special Material Identification Code (SMIC). These terms are discussed in the next chapter.

Descriptive/Identification Lists and Illustrated Shipboard Shopping Guides

Descriptive type catalogs or Identification Lists (IL's) are available on all Federal Supply Classification (FSC) group materials. These lists catalog material by what it is rather than by how it is used. These catalogs are similar to the Sears - Roebuck type catalogs, which have a comprehensive alphabetical index, group like items together, and throughly describe the items (size, weight, composition, etc.).

The Illustrated Shipboard Shopping Guides (ISSG) are similar in many ways to the IL's. They are designed to assit fleet personnel in identifying those items of supply not normally related to a part number or reference number to an FSN. They also provide assistance in determining substitute items by virtue of illustrations, specifications, and narrative descriptions from which data can be compared.

The ISSG is a multivolume publication consisting of an introduction and master index plus a number of individual sections applicable to material in the specific federal supply classes or groups. The master index provides an alphabetical sequence listing of all item names included in the ISSG, with reference to the individual sections (FSC group or class) wherein they appear.

SOURCE AND ACCOUNTABILITY CODES

Source Codes

Source codes are symbols which indicate the source of supply for an item required to maintain or repair a component part of an aircraft. The source code for each item is listed in the Numerical Index of the IPB and in the Allowance List. Specifically, these codes indicate whether the item is to be requisitioned from the supply system; to be manufacturered; to be obtained from salvage; not to be installed; or, due to failure, is in need of complete overhaul or retirement of the assembly or equipment from service.

A complete list and definition of source codes are presented in the introductory pages of the IPB or Allowance List. The following are examples of source codes:

SOURCE CODE P1 is applied to items which are purchased in view of known or anticipated usage and which are impractical or uneconomical for military service manufacture.

SOURCE CODE MO is assigned to items to be manufactured at the organizational level of maintenance.

SOURCE CODE AF applies to items to be assembled at intermediate maintenance levels afloat.

SOURCE CODE NN applies to items designated to be purchased locally and not stocked in the Navy supply system.

Accountability Codes

Accounting for material does not cease when it is withdrawn from the supply department. It is at this point that the accounting responsibility passes to the applicable maintenance personnel.

The accountability codes used in allowance lists and most IPB's are known as Material Accountability Recoverability Codes (MARC's). MARC's are assigned only to aeronautical provisioned items to reflect the accountability, recoverability, and repair policy determined for an item of equipment of material required for the maintenance, repair, or rework of an end item. MARC is a system whereby a letter of the alphabet is used as a guidepost by personnel working with aviation material. This system helps personnel to determine the proper method of the following:

1. Requisitioning material with regard to inventory control and fiscal accounting procedures.
2. Accounting for material while in use.
3. Turn-in or disposition of material.
4. Repair or overhaul.

The following list defines the various material accountability codes.

B - Exchange Consumables. Code B is applied to items which are consumable or expendable but normally require item-for-item exchange for replacement. Such items may contain precious metals, may be highly pilferable, or may be high cost items.

C - Consumables. Code C is applied to all other consumable or expendable items which do not require item-for-item exchange for replacement.

D - Equipage, Support Type. Code D is applied to end items of support equipment which are economical and practical to repair on a scheduled basis through a major rework activity. Code D items are maintained on a custodial basis and normally require item-for-item exchange for replacement.

E - Equipage, Locally Repairable, Support Type. Code E is applied to end items of support equipment which are to be repaired locally by the using or fleet support activity within their assigned maintenance responsibility. Code E items are maintained on a custody basis and normally require item-for-item exchange for replacement.

R - Equipage. Code R is applied to repairable (except end items of support equipment) items which are economical and practical to repair on a programed basis through a major rework activity. Code R items are maintained on a custody basis in some cases, depending upon the use of the item. These items normally require item-for-item exchange for replacement.

L Equipage, Locally Repairable. Code L is applied to repairable (except end items of support equipment) items which are to be repaired locally by the using or fleet support activity within their assigned maintenance responsibility. Code L items are maintained on a custody basis in some cases, depending on the use of the item. They will normally require item-for-item exchange for replacement.

Source, Maintenance, and Recoverability Codes (SM & R)

A six-digit SM & R code will eventually replace the source and MARC's now being used. The actual code used to identify the source will remain the same.

Source, maintenance, and recoverability codes are used in the various IPB's and allowance lists to identify the source of spares, repair parts, and items of support equipment and the levels of maintenance authorized to maintain, repair, overhaul, or condemn them.

The coding controls the range of parts procured to support new equipments and expedite the maintenance, repair, and overhaul of aeronautical equipments by providing maintenance and supply personnel with the necessary information relative to the source of supply and, where applicable, the maintenance implications and recoverability status of items.

The SM &R code format consists of a 6-digit number comprised of three parts—a two-position source code, a three-position maintenance code, and a one-position recoverability code. The source code indicates the means of acquiring the item.

The third-position maintenance code indicates to maintenance and supply personnel the lowest level of maintenance authorized to remove and replace the item.

The fourth-position maintenance code indicates the lowest maintenance level authorized to accomplish repair, overhaul, or assembly of the item. Code Z in this position indicates that no repair is expected to be made at any level.

The fifth-position maintenance code indicates the lowest maintenance level authorized to condemn the items when repair or overahul at this level or higher level is not economically or militarily justified.

The recoverability code indicated in the sixth position indicates special instructions on reclamation or disposition actions required on the item. Use of this position is temporarily being held in abeyance pending greater Department of Defense standardization of the codes. Material accountability/recoverability codes (MARC's) are to be used separately pending approval of these codes for inclusion in the SM & R code format. An example of an SM & R code is PIHZH.

MATERIAL REQUISITIONING

Maintenance personnel are apt to encounter a variety of local requisitioning channels; all designed to present a demand for an item to the supporting supply department. Assigned levels of maintenance, geographical location of shops relative to supply facilities, and mission of activities requiring support all influence the local requisitioning channels. Local instructions normally promulgate detailed procedures for submitting your demand to the appropriate supply point.

SUPPLY ACTIVITY

The mission of the supply activity is to support the operational and maintenance efforts of the activity/ship. Stocks of aviation oriented material carried are tailored and replenished to this end. Positioning, replenishment, and control of stocks of material in maintenance areas are carried out as a result of joint decisions by the Supply and Maintenance Officers concerned. They determine the range, depth, and related procedures. The Navy Maintenance and Material Management System (Aviation) requires that the cost of material used in maintenance be determined and accumulated in such manner and detail that weapons system costing can be measured. Usage is finely defined as to stock number, within component, within equipment/weapon/aircraft, in a particular squadron, located in a specific operational area, at a definite point in time. These data are used as an inventory management tool to determine geographic and strategic distribution of stock of material. In addition, the data will be invaluable in establishing the material portions of work standards in maintenance.

Supply Support Center

Maintenance organizations have one single point of contact with the supporting supply activity. This single supply contact point is the Supply Support Center (SSC) which responds to all material requirements of the maintenance organizations. The SSC is an internal organization of the local supply activity. It is made up of two sections—the Supply Response Section (SRS) and the Component Control Section, (CCS).

Supply support is available consistent with the operating hours of the maintenance activities supported. If maintenance is being performed 24 hours a day, then supply support is available 24 hours a day.

The supply support center maintains rotatable pool material which consists of repairable ready-for-issue items reserved primarily to satisfy the requirements of Organizational level maintenance. Items maintained in the pool are capable of being repaired by the local Intermediate maintenance activity. They must have application to weapon systems supported by local Intermediate maintenance activities and have an average Organizational maintenance level removal rate of at least one per month. Defective components are turned in to Intermediate level maintenance for repair. The defective components repaired to an RFI condition are then returned to the rotatable pool to replace the components previously issued.

Low value, fast moving consumable items are preexpended from supply. Such materials are located in the maintenance area. The establishment, maintenance, and replenishment of preexpended bins are the responsibility of the supply support center.

SUPPLY RESPONSE SECTION.—The Supply Response Section (SRS) is responsible for preparing all necessary requisitions (DD Form 1348) and related documents required to obtain material for local maintenance use in direct support of weapon system maintenance. The maintenance organization verbally notifies the supply organization of the need for such material. When material is available locally, the time frame for processing and delivery is as follows:

Priority	Process/Delivery Time
1-3	1 hour (NORS/NFE)
4-8	2 hours
9-20	24 hours

Otherwise, the time frames as noted in table 3-2 will apply.

Table 3-2.—Processing time frames.

Issue group	Issue priority designator range	Supply source processing	CONUS on station time	Overseas on station time
1	1-3	24 hours 24-hour day 7-day workweek	120 hours	168 hours
2	4-8	72 hours 24-hour day 7-day workweek	8 days	15 days
3	9-15	10 days 8-hour day 5-day workweek	20 days	45 days
4	16-20	12 days 8-hour day 5-day workweek	30 days	60 days

The SRS is responsible for receipt, storage, and issuance of all ready-for-issue pool components. It is responsible for physical delivery of RFI material to maintenance organizations, and the pickup of defective components from the Organizational maintenance activity and subsequent delivery to the Intermediate maintenance activity. Actual maintenance personnel are not involved in the physical movement of material between organizations.

This section also performs technical research in regard to completion of requisition documents as well as determining the status of outstanding requisitions and relaying this status to the customer upon request.

COMPONENT CONTROL SECTION.—The Component Control Section (CCS) accounts for all components being processed in the Intermediate maintenance activities. This section also maintains records on the status of all rotatable pool components.

MATERIAL CONTROL DIVISION

The material control division at the organizational level is responsible for providing support and services to the production divisions as follows:

1. Requisition and expedite materials required to support the command.

2. Initiate surveys in the event of loss, damage, or destruction of accountable material/ equipment.
3. Verify NORS (Not Operationally Ready Supply) requisitions.
4. Maintain accountability of material authorized by the allowance lists, IMRL's, etc.
5. Establish pickup and delivery points for material.
6. Maintain the material control register or facsimile.
7. Perform cost and allotment accounting.
8. Maintain aircraft inventory logs.
9. Pass all requirements for material required for direct support of weapon system maintenance to the SSC. A Material Control Register is maintained for these items.
10. Prepare documents for material required for indirect support of weapon systems maintenance. Examples of materials for which documents are to be prepared are aviation fuels and lube oils, rags, and flight jackets. A separate requisition record log is maintained for these items.
11. Maintain liaison with the supporting SSC on maintenance material matters to insure that material needs of the organization are satisfied.
12. Furnish technical advice and information to the supply activity on the identity and quantity of supplies, spare parts, and materials required for maintenance actions.
13. Establish procedures to insure the periodic inventory of tools and the adequate accountability of material and equipment on custody to the cognizant organization.
14. Keep maintenance control advised of the overall supply situation as it affects the activity.

Material control is responsible for the coordination of material ordering, receipt, and delivery. This is done in such a manner as to insure that the correct material is ordered and that it reaches the work center within the specified time frame.

MILSTRIP

The Military Standard Requisitioning and Issue Procedure (MILSTRIP) and Uniform Material Movement and Issue Priority System (UMMIPS) were developed by the Department of Defense to provide a common supply language and more effective supply system operations within the military establishment. This system standardizes forms, formats, codes, procedures, and the priority system.

MILSTRIP employs two forms for the requisitioning and issuing of material. The Single Line Item Requisition Document (Form DD 1348) is the basic request document submitted to the applicable supply echelon for material requirements. The issue document is the Single Line Item Release/Receipt Document (Form DD 1348-1). Form DD 1348-1 is also used to return RFI material to the supply system. These forms will be prepared by the Supply Response Section of supply for all material requested in direct support of weapon system maintenance and by the material control work center for material requested in indirect support of weapon system maintenance.

Uniform Material Movement and Issue Priority System (UMMIPS)

In this system, the priority designator is determined by a combination of factors which relate the military importance of the requisitioner (force/activity designator) and the urgency of need or end use (indicated by an urgency-of-need designator). The force/activity designator (a roman numeral I-V) is assigned by the Joint Chiefs of Staff (JCS), Chief of Naval Operations (CNO), and Navy commanders. The urgency-of-need designator (an alphabetical letter) is determined by the requisitioning activity, with certain exceptions. These two factors will enable the requisitioning activity to determine the UMMIPS priority designator (arabic numeral).

The twenty priority designators provided in UMMIPS have been placed into four priority groups. Each priority group qualifies for different processing time standards as prescribed in table 3-2. These priority groups are compatible with the transportation priorities prescribed in the Military Standard Transportation and Movement Procedures (MILSTAMP).

1. Force/activity designators.
    a. A force/activity is:
        (1) A unit, organization, or installation performing a function or mission.
        (2) A body of troops, ships, or aircraft, or a combination thereof.
        (3) A function, mission, project, or program, including those under military assistance (grant aid and/or sales).
2. Selection and assignment of issue priority designators for requisition and issue transactions.
    a. All requests for material normally stocked in a supply system will be assigned an

issue priority designator. The issue priority designator normally expresses the relationship between the force/activity designator and the urgency-of-need designator. However, there are certain exceptions and unusual circumstances under which a requisitioning activity is authorized to assign a specific numerical priority designator that represents a uniform need for an item regardless of the force/activity designator assigned. These exceptions are as follows:

(1) A priority designator of 03 will be used by all activities regardless of force/activity designator in requisitioning high value items required for immediate use; i.e., where urgency-of-need designators A or B are indicated.

(2) A priority designator of 03 will be used by all activities, regardless of force/activity designator, for medical or disaster supplies or equipment required immediately for prolonging life in case of critical injury, fatal disease, or natural emergency.

(3) A priority designator of 06 will be used by all activities, regardless of force/activity designator for the replenishment of high value items.

(4) A priority designator of 06 will be used by all activities regardless of force/activity designator, for individual and organizational clothing required to provide a minimum of essential clothing in the event active duty military personnel are without the clothing required.

b. Except for conditions referenced above, the requisitioner will:

(1) Select the applicable urgency-of-need designator for each requisition or order.

(2) Ascertain the appropriate issue priority designator for the force/activity designator assigned the requisitioning activity and the applicable urgency-of-need code, and enter this number on the material requirement document (NAVSTRIP requisition).

c. Supply activities, when requisitioning a specific requirement for a supported unit with a different force/activity designator than the supplying activity, will use the priority designator appropriate to the requiring activity.

3. Every activity is assigned 1 of 5 force/activity designations according to their military importance. (See table 3-3.) These designators are as follows:

Table 3-3.—Priority number chart.

Designator	A Unable to perform	B Impairs capability	C Other than routine	D Routine
I Combat	1	4	11	16
II Positioned	2	5	12	17
III Ready	3	6	13	18
IV Reserve and support	7	9	14	19
V Others	8	10	15	20

I - COMBAT—The highest order of military importance. This designator is not normally used in peacetime unless approved by the President or the Joint Chiefs of Staff.

II - POSITIONED—United States combat, combat ready, and direct combat support forces deployed outside CONUS in specific theaters or areas designated by the Joint Chiefs of Staff and those CONUS forces being maintained in a state of combat readiness for immediate (within 24 hours) deployment or employment.

III - READY—All other United States combat ready and direct combat support forces outside CONUS not included under designator II.

IV - RESERVE AND SUPPORT—U. S. active and selected reserve forces planned for employment in support of approved joint war plans. This category includes training units and units in training for schedules deployment.

V - OTHERS—All units not otherwise assigned, including administrative/staff type units.

4. The urgency of need for an aircraft spare part or aeronautical material may be determined in accordance with the following designators (A, B, C, and D):

A - Emergency requirements for primary weapons, equipment, and material for immediate use without which the unit concerned is unable to perform assigned operational missions (NORS), or such condition of readiness is imminent. (See notes 1 and 2.)
Material required for immediate installation on or repair of primary weapons and equipment, without which the unit concerned is unable to perform assigned operational missions (NORS), or such condition of readiness is imminent. (See notes 1 and 2.)
Items required for immediate end use in direct support of equipment essential to the operation of aircraft and equipment (e.g., ground support, firefighting, etc.), or such condition of readiness is imminent. (See notes 1 and 2.)

B - Item(s) required for immediate end use, the lack of which is impairing the operational capability of the aircraft or organizational unit concerned. The aircraft or organizational unit concerned can operate only temporarily as an effective unit; assigned operational missions can be accomplished, but with decreased effectiveness and efficiency.
Item(s) required for immediate end use to effect repairs to aircraft and aircraft support equipment, without which the operational capability of the aircraft is impaired or effectiveness in accomplishing assigned missions is reduced.
Item(s) required to effect emergency repair or replacement of intermediate maintenance activity equipment essential to providing services for aircraft and aircraft equipment.

C - Items required for immediate end use to repair or replace administrative support equipment and equipment or systems not essential to operational missions of aircraft or organizational units.
Items essential to initial outfitting or to completion of allowance/load lists on a more urgent basis than routine stock replenishment.
Material required to preclude a work stoppage or prevent delay in scheduled maintenance of weapons systems or major equipment.

D - Items required for routine stock replenishment.
Items required for initial outfitting and filling of allowances.
Items required for scheduling maintenance, repair, or manufacture of supply system stocks.

NOTE 1: Requirements of this nature are of such a consequence as to require a report to higher authority of a degradation of the requisitioning units capability.

NOTE 2: An imminent condition of degraded readiness exists when material is required to prevent an Anticipated Not Operationally Ready Supply (ANORS) condition. An ANORS condition will exist when it is known that items of material or equipment, not available in the unit, are required within the following time frames:

a. Five (5) days for nondeployed units.
b. Seven (7) days for deployment units.
c. Fifteen (15) days for Vietnam requirements.

PREEXPENDED BINS

Common repair parts that are considered to be high in usage and low in unit cost are expended from Supply Department stock records and related financial accounts for placement in preexpended bins. The supply officer is primarily responsible for proper management and maintenance of preexpended bins, including display, labeling, and initiating replenishment or turn-in action when required. Recurring issues of consumable items for the repair of equipment are preexpended candidates. Such items are usually general purpose hardware (nuts, bolts, etc.), consumable repair parts (resistors, capacitors, etc.), and bulk material (electric wire, lubricant, etc.). Items having a unit cost of $10.00 or less may be preexpended. The maximum inventory of any one item at any one outlet must not exceed a 30-day estimated supply. Items having a unit cost exceeding $10.00 may be preexpended with approval of the commanding officer.

Specific items added to or deleted from preexpended bins are determined jointly by the supply officer and the maintenance officer having cognizance over the shop in which such bins are located. Preexpended bins will be established in areas where maintenance is being performed and should be located in these maintenance areas where they are readily accessible to maintenance personnel.

ROTATABLE POOLS

Rotatable pools consist of a range of selected components maintained by a specific maintenance activity, on custody from the supporting supply department. The items generally carried in the pool are those required to sustain operations where immediate availability is essential. To be included in the pool, an item should meet all of the following conditions:

1. Be capable of repair by the local AIMD.
2. Have application relationship to weapons systems supported by the local AIMD's.
3. Have an average removal rate of at least one per month.

An official list of pool items is prepared by the supply officer and provides a ready reference for components carried in pools. Lists are distributed to supply and maintenance units as required and include manufacturer's part number, manufacturer's code, FSN, WUC, nomenclature, and item number in various combinations. Organizations need a list in WUC sequence and another list in part number sequence showing the various part numbers and FSN's used to order an item.

HIGH VALUE ASSET CONTROL MATERIAL

The High Value Asset Control (HIVAC) program is a program of high value item management for the Department of the Navy. The purpose of this program is to achieve inventory economics, without impairing combat readiness, through specialized management of certain high value items. Items subject to the HIVAC system are designated as such by the applicable inventory manager, based on the volume of their annual demand and their unit price.

Although the technician is not directly involved in the program, he is involved at fleet level in that some of these items will be installed in aircraft or held in rotatable pools for which he may be required to assume responsibility. The major responsibility of fleet personnel is supply discipline, since supply discipline in the fleet is an especially critical aspect of the high value program. This is because of the greater difficulty of maintaining accountability under the pressure of operating conditions. Also, prompt action on the part of fleet personnel to expedite handling of high value items is essential to the program. For complete and detailed information concerning the HIVAC system, refer to SecNavInst. 4440.29 (Series) and NavSupInst. 4440.105 (Series).

AIRCRAFT MAINTENANCE MATERIAL READINESS LIST (AMMRL) PROGRAM

This program has provided for the development of data and documentation needed to determine and establish firm support equipment requirements and inventory control of aircraft maintenance support equipment. The objective of this program is to document factual data and in-use asset information concerning the support equipment which can be used by management for the following purposes:

1. The determination and establishment of allowance requirements for support equipment at Intermediate and Organizational maintenance activities.
2. Redistribution of in-use assets.
3. To provide a base for budgeting of support equipment.
4. To measure material readiness in view of support equipment availability.

The Aircraft Maintenance Material Readiness List Program was initially established by BuWeps (now NavAir) in May, 1960, for the management of ground support equipment. Prior to that time, each fleet aircraft maintenance activity was required to consult many varied types of allowance lists covering support equipment and determine their own requirements. However, BuAer (which evolved to BuWeps and now NavAir) and ASO were determining overall fleet requirements two or three years prior to the time fleet activities determined their requirements. In most cases the BuAer/ASO determinations did not agree with those made by the fleet activities. In addition, there was no provision for feedback information to BuAer and ASO of equipment that the fleet activities had on hand. There were no reliable facts on which to determine requirements and to provide budgeting information and this resulted in inaccurate procurements and distribution of support equipment assets.

These problems resulted in the development of the AMMRL program which provides a means of determining immediate and forecasted requirements for each activity.

The proper determination, budgeting, acquisition, and distribution of support equipment is the ultimate responsibility of NavAirSysCom. However, the bulk of the day-to-day work concerning the maintenance of records for equipment in-use and the location of this equipment is placed with the NavAirSysComReps LANT/PAC/Pensacola. They represent NavAir within geographical areas of responsibility. NavAirSysComRep Pensacola's responsibility encompasses all of the naval air training activities. Some of the NavAirSysComRep's responsibilities include:

1. Scheduling, preparing, and maintaining Individual Material Readiness Lists for all Navy aircraft maintenance activities.
2. Obtaining in-use inventories and maintaining inventory data.
3. Maintaining an Application Data for Material Readiness List (ADMRL) file.
4. Furnishing consolidated inventory reports to NavAir for activities within their area of responsibility.
5. Participating in ADMRL technical review conference and AMMRL review boards.

APPLICATION DATA MATERIAL READINESS LIST (ADMRL)

This is a master list used to specify the requirements for each item of aircraft maintenance support equipment against each level of maintenance and selected ranges of each aircraft, engine, propeller, and system for which each item is needed. For example it contains allowances for all the support equipment required to support the P-3C aircraft on both the AIMD and a squadron level, based on the number of aircraft (for the squadron) or the number of systems, supported (for the AIMD). This data is developed primarily from Aeronautical Allowance Lists. ASO maintains the master updated ADMRL on tape and furnishes it to the NavAirSysComReps when required. ASO enters all technical changes such as changes in quantity, additions of new items, deletions, or changes of maintenance levels, as approved by NavAir.

From this master file (ADMRL), the Individual Material Readiness Lists (IMRL's) are prepared. For example, when a squadron gets a completely new type of aircraft, the NavAirSysComRep can extract the allowances of support equipment required for Organizational level maintenance for that type and number of aircraft and construct an IMRL which becomes the squadrons allowance for support equipment.

INDIVIDUAL MATERIAL READINESS LIST (IMRL)

The IMRL specifies items and quantities of aircraft maintenance support equipment required for material readiness of the aircraft maintenance activity to which the list applies. As previously indicated, this list applies to an activity by name. The list is prepared by extracting from the ADMRL those applicable portions which pertain to the specific aircraft and maintenance material assignments of the activity for which the list is being prepared.

The IMRL should be continually reviewed and updated by each activity to support current and anticipated changes in aircraft maintenance support equipment requirements. Because the IMRL is continually reviewed and updated and approved by the cognizant command, it is the firm mandatory material readiness list of the activity to which it applies. Maintenance of the IMRL usually becomes the responsibility of the senior AK attached to the activity to which it applies. Maintenance of the IMRL at the maintenance activity level consists of the following:

1. Establishment of procedures for control and custody of accountable IMRL equipment.
2. Reporting all transactions involving the permanent transfer, receipt, or condition change (loss, etc.) of IMRL items.
3. Conducting an annual physical inventory and submission of the annual inventory of IMRL equipment to the appropriate NavAirSysComRep.
4. Insuring that all shortages are ordered and followed up on as necessary.

5. Consolidating, preparing, and submitting requests for IMRL changes to the appropriate NavAirSysComRep.

Inventory and maintenance of an IMRL that meets the needs of the activity requires the cooperation of all maintenance supervisors. If the lack of appropriate equipment detracts from the activitys capability to perform certain maintenance tasks and the item is not on the activity's IMRL, addition of the item should be requested with adequate justification for the change in requirements. If an item on the IMRL is not required or the quantities are in excess of actual needs, again justify this fact and have the item deleted or a new allowance established so that the item may be redistributed as appropriate or dropped from the ADMRL master file. Annual physical inventories will require joint inventory by the AK maintaining the IMRL and the supervisors in charge of the IMRL equipment.

CHAPTER 4

MAINTENANCE PROCEDURES AND SPECIAL PROBLEMS

The term "testing," as used in this chapter is considered to consist of measurements, tests, and checks. When these measurements, tests, and checks are applied to electronic equipments (or systems), they may provide information which establishes an acceptable condition, or they may provide information of undesirable conditions which exist in these equipments.

In the former instance, the testing (and inspection) proves that the equipments are operating within tolerances, and results in establishing a form of maintenance which is preventive in nature. In the latter instance, the testing (and inspection) exposes conditions which are undesirable, and which must be corrected if the equipments are to perform as designed. The result of this testing establishes another form of maintenance which is corrective in nature.

By applying both preventive and corrective maintenance, electronic equipments are kept in continuous service at optimum or peak performances that are reasonably close to the standards set by the manufacturing specifications.

Senior technicians should study and constantly refer to the available maintenance publications covering the equipments used by their activity. They should stand ready to answer questions about equipments, and to outline the various steps necessary to correct possible troubles.

MAINTENANCE PROCEDURES

Performance testing data, along with other maintenance information, is covered in the Service Instruction Manual for each particular equipment. This information has been written to enable the technician to make an intelligent evaluation of the operating capabilities of that equipment; at the same time the data serves as a gage for the measurement of equipment efficiency. The standards are designed to insure that equipments operate at maximum effi ciency at all times, and to reveal any change from this optimum performance, thus indicating the need for corrective measures.

The information presented in these manuals gives the technician a step by step performance check with all the test connections and test equipment clearly indicated for each step. Performance testing is discussed to show the relationship between that type of testing and preventive maintenance, as a means of emphasizing that the final results may indicate the need for corrective maintenance. Both preventive maintenance and corrective maintenance are discussed in the following paragraphs. Troubleshooting—considered as the principal form of corrective maintenance—is analyzed in detail.

PREVENTIVE MAINTENANCE

The best maintenance work is preventive in nature, potential failures being detected and corrected before they have a chance to develop. Preventive maintenance is defined as those measures taken periodically, or when needed, to achieve maximum efficiency in performance, to insure continuity of service, and to lengthen the useful life of the equipment or system. This form of maintenance consists principally of cleaning, lubrication, and periodic inspections aimed at discovering conditions which, if not corrected, may lead to malfunctions requiring major repair.

Performance Testing

A performance test is an operational check of equipment in which the performance specifications set by the manufacturer are carefully observed. It should be a part of an overall program of inspections and tests in which accumulative data on each equipment is systematically compiled.

Inspections fall into two main categories. First, there is the regular visual inspection of the mechanical aspects of the equipments. This is conducted for the purpose of finding dirt, corrosion, loose connections, mechanical defects, and other sources of trouble. Second, there are functional inspections that are accomplished through periodic tests and through less frequent bench tests. To realize the most effective results from the regular functional inspections, a careful record of the performance data on each equipment must be kept.

The value of performance data records is demonstrated in a number of ways. Comparison of data taken on a particular equipment at different times reveals any slow, progressive drifts that may be too small to show up significantly in any one test. While the week to week changes may be slight, they should be followed carefully so that necessary replacements or repairs may be made before the margin of performance limits is reached. Any marked variations should be regarded as abnormal, and should be investigated immediately.

Another advantage in keeping systematic records of performance and servicing data is that maintenance personnel develop a more rapid familiarization with the equipment involved. The accumulated experience contained in the records furnishes a guide to swift and accurate troubleshooting.

Test Methods

The actual work of testing and servicing, as well as that of recording performance data, should be done systematically. While a logical sequence of steps is required, this does not imply the rigid necessity of making only a step by step progression. Working within the overall pattern of procedure, maintenance personnel should analyze the results obtained to eliminate unnecessary steps.

GENERAL RECEIVER TESTING.— Receivers are composed of a series of selective circuits, each stage of which is designed to refine and amplify the output of the preceding stage. The lowered efficiency of any one circuit results in lowered overall efficiency of the receiver. The sensitivity of the receiver may also be decreased by the misalinement of the successive circuits, each of which may function in a suitable manner as a unit.

The function of a receiver is to receive (in a selective manner) a weak signal; therefore, an objective overall test on sensitivity is the most significant single check that can be made of the condition of a receiver.

Some receivers are provided with a built-in output meter, and others have an output meter equipped with a cord and plug to facilitate testing. The only other requirement for a sensitivity check is a suitable standard signal for the excitation of the receivers on the various bands. This signal may be provided by a calibrated signal generator coupled directly to the receiver input. Any decrease in sensitivity should be corrected as soon as possible by following the appropriate remedial procedures.

In addition to periodic checks on sensitivity, routine physical inspections must be made of the receiver and accessory units. Lubrication and cleaning schedules recommended by the manufacturer should be followed. Tubes should be tested sparingly, because frequent insertion and removal weakens socket contacts and causes noisy (or intermittent) operation.

Electron tube and transistor life extends to several thousand hours. Therefore, in equipment which is continuously operated and on which periodic sensitivity tests (or operation records) are made, tubes and transistors should be checked only when poor performance indicates such a need. When tubes or transistors are replaced in RF circuits, the circuit should be checked and, if necessary, realined to achieve normal sensitivity. Before new tubes or transistors are used, it is a good practice to check the tubes on a tube tester of the transconductance type, and the transistors on a transistor tester.

GENERAL TRANSMITTER TESTING.—In some transmitters, circuit currents are automatically measured by self-contained instruments. If these readings are periodically recorded, the cumulative record bears the same relationship to the transmitter as a sensitivity check does to the receiver.

Ventilation and dust conditions present a greater problem in transmitters than they do in receivers, principally because there is more heat to be dissipated. Because dust forms a film which absorbs moisture, the insulation resistance is lowered to a point at which flashover (arcing) can occur. Therefore, cleaning periods must be initiated and regularly followed. These periods will vary for different locations.

Insulators must be wiped, corroded metal parts cleaned, and arc-overs repaired. It is possible to detect poor contacts by inspecting for evidences of local overheating (or arcing). Such contacts must be thoroughly cleaned and tightened. Likewise, it is important that the antenna connections be regularly inspected and cleaned.

CORRECTIVE MAINTENANCE

Corrective maintenance consists of the location and correction of troubles whenever an equipment or system fails to function properly. Location of the trouble includes the activities of evaluating reported discrepancies and troubleshooting.

The trouble may be corrected by mechanical or electrical adjustments, or it may be necessary to replace one or more parts.

Evaluation of Reported Discrepancies

When a discrepancy is turned in either by crew debriefing or on a "gripe sheet," the first thing to determine is whether the system or equipment is actually faulty. A mistake which is often made is removing the equipment from the aircraft before checking it.

The supervisor should have a prescribed procedure for technicians to follow in checking a discrepancy on equipment installed in an aircraft. Some suggested procedures that will aid in evaluating discrepancies are as follows:

1. Visual inspection. A visual inspection of the equipment in the aircraft may disclose frayed or broken wiring, loose connections (electrical and mechanical), or open circuit protectors, which could cause the malfunction.
2. Operational check. An operational check of the system can aid in analyzing the discrepancies and pinpointing the trouble to a particular unit. In some cases, it may disclose improper operating procedures—especially with newer type equipment or new personnel.
3. Performance checks. The use of portable test equipment, built-in meters, and special test equipment installed in some types of aircraft, will aid in making a performance test of the system in the aircraft. Performance testing, mentioned in the first part of this chapter, should be of great help in localizing the discrepancy to a particular unit which can be removed from the aircraft for repair, or in some cases, repaired in the aircraft.
4. Quality assurance inspections. Highly qualified senior technicians should be provided to conduct thorough inspections on all equipments prior to their installation in the aircraft. This quality assurance inspection should be a combination of the visual inspection, operational check, and performance check. This inspection will ascertain that each equipment is in proper operating order and completely mission ready.

Troubleshooting

Corrective maintenance is, for the most part, concerned with troubleshooting, which can be further divided into two phases. The first phase is system troubleshooting. It is based on the starting procedure, and is designed to isolate the malfunction to the unit in which the trouble exists.

The second phase is unit troubleshooting, and is designed to locate the trouble in the unit in which it occurs. In rare cases it is possible to determine which unit is at fault without following the system troubleshooting method to isolate the unit. However, most of the time it is impossible to determine which unit is at fault until the system method has been employed in whole or in part.

TROUBLE ISOLATION.—When abnormal operation has been traced to a particular stage or to a functionally related group of stages, its cause must be further isolated and identified as due to a particular faulty component or group of components. To do this it may be necessary to disassemble the equipment, either in whole or in part. After disassembly, the trouble may be immediately apparent through a mere visual inspection, whereupon the trouble should be corrected by repair or replacement.

If the trouble is not immediately apparent, a more detailed procedure should be followed to isolate and repair or replace the actual circuit component responsible for the failure. This procedure consists of tube or transistor checks, voltage and resistance checks, waveform analysis, and finally, repair or replacement of the defective component.

Supervisory personnel should insure that detailed trouble isolation procedures are in accordance with the applicable current Service Instruction Manual for the equipment being repaired.

TUBE TESTING.—Electron tube failures are responsible for a large percentage of troubles that occur in equipment or systems. However, if a particular system uses a great number of tubes, it is obviously impractical, and not good policy, for a technician to attempt to locate faults by general tube checking. Only when the fault has been traced to a particular stage should any tubes be tested, and then only those associated with the improperly functioning circuits.

When replacing a tube in a circuit, the technician should note and record the positions of the equipment controls before changing the setting of any of them. If adjusting the controls with the new tube in place does not correct the abnormal condition, the controls should be returned to their original positions. Unless a reliable tube tester shows the original tube to be defective, the old tube should be returned to the original circuit.

In many high frequency equipments, the interelectrode capacitance of a tube is a significant portion of a tuned circuit; therefore, when tubes are changed, the tuning of the circuits may be upset. Thus, if too many tube substitutions are made, the unit may become misalined.

VOLTAGE MEASUREMENTS.—Since many troubles encountered in equipments and systems either result from abnormal voltages or produce abnormal voltages, voltage measurements are considered an indispensable aid in locating troubles. Testing techniques that utilize voltage measurements also have the advantage that circuit operation is not interrupted. Point to point voltage measurement charts which contain the normal operating voltages encountered in the various stages of the equipment are available to the technician. These voltages are usually measured between the indicated points and ground unless otherwise stated.

When making voltage measurements, it is good practice to set the voltmeter on the highest range initially so that any excessive voltage in a circuit will not damage the meter. To obtain increased accuracy, the voltmeter may then be set to the designated range for the proper comparison with the representative value given in the voltage charts.

If the internal resistance of the voltmeter and multiplier is approximately comparable in value to the resistance of the circuit under test, it will indicate a considerably lower voltage than the actual voltage present when the meter is removed from the circuit. The sensitivity (in ohms per volt) of the voltmeter used to prepare the voltage chart is always given on the charts. Therefore, if a meter of a similar sensitivity is available it should be used so that the effects of loading will not have to be considered.

When checking voltages, it is important to remember that a voltage reading can be obtained across a resistance, even if the resistance is open. The resistance of the meter and the multipliers forms a circuit resistance when the meter probes are placed across the open resistance. Thus the voltage across the component may appear to be normal when the meter is connected, and abnormal when it is disconnected. If the voltages appear normal on a faulty stage, the next step would be to perform a resistance check of that stage.

NOTE: Certain precautions are presented in Basic Electricity, NavPers 10086-B, as general safety measures pertinent to the measurement of voltages. Supervisors should ascertain that these precautions are adhered to by all personnel who are responsible for the maintenance of electronic equipment.

RESISTANCE MEASUREMENTS.—Defective components can usually be quickly located by measurement of the d-c resistance between various points in the circuit and a reference point or points (usually ground). This is true because a fault will generally produce a change in resistance values. Point to point resistance charts can be used advantageously at this time. The values given, unless otherwise stated, are measured between the indicated points and ground.

Before making resistance measurements, the technician must be sure that the power to the equipment under test has been turned off. Since an ohmmeter is essentially a low range voltmeter and a battery, an ohmmeter connected to a circuit which already has voltages in it may be seriously damaged. The pointer may be deflected off scale, and the meter movement may be permanently damaged.

Filter capacitors must be discharged before making resistance measurements. This is extremely important when testing power supplies that are disconnected from their loads. If a capacitor discharges through the meter, the surge may burn out the meter movement. Furthermore, contact with a circuit containing a charged capacitor may endanger the life of the person making the test.

WAVEFORM COMPARISON.—The measurement and comparison of waveforms are considered to be very important parts of the circuit analysis used in troubleshooting. In some circuits (for example, pulse circuits) waveform analysis in indispensable. Waveforms may be observed at test points, shown in the waveform charts which are part of the maintenance literature for the equipment. It should be noted that the waveforms given in the instruction books are often idealized and do not show some of the details which are normally present when the actual waveform is displayed on an oscilloscope.

By comparing the observed waveform with the reference waveform, faults can be localized rapidly. A departure from the normal waveform indicates a fault that is located between the point where the waveform is last seen to be normal and the point where it is observed to be abnormal. (For example, if a waveform is observed to be normal at the grid circuit and abnormal at the plate circuit of the same stage, this indicates that the trouble lies in that stage or possible the input of the following stage.)

When waveforms associated with a multivibrator, a blocking oscillator, or a similar circuit are observed to be abnormal, replace the associated tube before making further tests. If the replacement tube does not provide the correct waveform, reinsert the original tube.

If there is no trouble present in an equipment or system, a waveform observed at a point in the equipment should closely resemble the reference waveform given for that test point. The reference waveforms supplied with maintenance literature are the criteria of proper equipment performance. However, test equipment characteristics or usage can cause distortion of the observed waveform, even though the equipment or system is operating normally. Several of the most common causes of these conditions are summarized as follows:

1. The leads of the test oscilloscope may not be placed in the same manner as those used in preparing the reference waveforms, or the lead lengths may differ considerably. This is particularly significant in the case of shielded test leads, where the capacitance per unit length is a factor.
2. A type of test oscilloscope having different values of input impedance, different sweep durations, or different frequency response may have been used.
3. The equipment operating (and servicing) controls may not have settings identical to those used when the reference waveforms were prepared. This condition is normally to be expected when servicing adjustments are made in terms of their effect on the shape and amplitude of an observed waveform.
4. The vertical or horizontal amplitudes of the reference and test patterns may not be proportional. This will produce apparent differences between the waveforms when actually there is no difference.

Whether or not a minor waveform discrepancy may be desregarded depends upon the type of circuit being traced. A minor discrepancy is not regarded as significant unless the nature of the discrepancy indicates faulty operation of the equipment. In general, time should not be wasted in searching for faults when relatively minor differences are detected between the reference waveforms and those obtained by test.

Microcircuit Modules

The demand for small, maintainable circuitry in military equipment has led to many different construction techniques. One of the most popular is microcircuit modules. Since microcircuit modules incorporate several subminiaturized features not found in conventional equipment, some specialized knowledge and tools are required for efficient repair and maintenance.

A few definitions are helpful in understanding the terms involved. Microelectronics is defined as "Electronics construction in the form of semiconductor integral circuits, thin film circuits, and combinations of these." (A thin film circuit is a circuit whose elements are films formed on an insulating substrate.) A microcircuit module is an assembly of microelectronic circuits performing one or more distinct functions in an electronic equipment or subassembly, constructed in and independently packaged, replaceable unit. An equipment which consists of replaceable assemblies (any type) is said to be of unitized construction. Microcircuit modular construction, then, is a type of unitized construction consisting predominantly of microcircuit modules.

The ultimate objective in the area of military electronics is to provide equipment which satisfactorily fulfills the military need with a high probability of no failure for the entire lifetime of the equipment. The higher the equipment reliability, the higher becomes this probability and the simpler becomes the logistic support problem.

Because of the increased reliability of microcircuit modules, less frequent repair of these items is expected when compared to conventional electronic items. Furthermore, because of the complexity, close tolerances and the increasing use of multilayer interconnections in the construction of microcircuit modules, repair of these items often requires sophisticated diagnostic equipment, special tools, and specialized personnel training.

When a microcircuit module is to be repaired, the repair will normally take place at the depot maintenance level. Depot level activities will be provided logistic support including test equipment for component fault isolation and spare parts to accomplish the repair. Maintenance performed on modular equipment by organizational level activities is limited to removal and replacement of the aircraft replaceable assemblies that are found to be faulty through the use of built-in test equipment or line test sets. Normally, intermediate maintenance activities are limited to fault isolation of defective subassemblies or microcircuit modules and testing to insure serviceability of these subassemblies and modules. However, selected intermediate maintenance activities are authorized (by higher authority) to perform depot level maintenance on specific microcircuit modules (this does not mean blanket authority for repair of all microcircuit modules coded for depot level repair) when the intermediate level activity successfully demonstrates that the activity has the skills, equipment, facilities, trained personnel, and technical data to accomplish the task in question. When authorization is granted to repair specific microcircuit modules at the intermediate maintenance level, spare parts and other necessary logistic support will be provided.

Repair of Defective Components

One of the time-consuming elements of troubleshooting is the identification of specific components. In conventionally wired equipment, components are not always easy to locate; even the circuitry in the chassis can become confusing since related components are often positioned in decentralized areas of the chassis.

In equipment which includes printed circuit boards, identification of circuitry and components may be relatively simple. This type of circuit construction allows uniform placement of components and complete sectionalization of related circuitry. Just a quick, once-over glance of such circuitry is often all that a technician requires to formulate the overall layout of the chassis in his mind and quickly focus his attention on the area of particular concern.

Many of the commercial manufacturers have developed methods of quick identification. One of the most common ways is to impose a grid over a drawing of the board, and then furnish a table which lists the part location. Another technique is to number points of interest on the schematic, then provide a pictorial guide to locate the points on the board.

Circuit tracing of the printed wiring board may be simpler than that of conventional wiring, due to increased uniformity. If the wiring board is translucent, a 60-watt light bulb placed underneath the side being traced will facilitate circuit tracing. Test points can be located in this manner without viewing both sides of the board.

Resistance or continuity measurements of coils, resistors, and some capacitors can be made from the component side of the board. In some cases, a magnifying glass will help in locating very small breaks in the wiring. Voltage measurements can be made on either side of the board. However, a needlepoint probe is needed to penetrate the protective coating on the wiring. Hairline cracks can be located by making continuity checks.

A number of general precautions are necessary when working with modular assemblies. Supervisory personnel should take steps to insure that the technicians in their shop or maintenance crew know and understand the rules set forth in the following paragraphs:

1. Observe power supply polarities when measuring the resistance of the circuits of modular assemblies containing transistors, or other semiconductors. Such parts are polarity- and voltage-sensitive. Reversing the plate voltage polarity of a triode vacuum tube will keep the stage from operating, but generally will not injure the tube. However, reversing the voltage applied to a transistor, or other semi-conductor, could destroy it very quickly.

Since transistors and similar components require different power supply connections, the personnel who work with these parts must always be alert in connecting test equipment. Make sure that the correct polarity and range are observed. Recheck your work before turning on the power—the wrong polarity will destroy the part.

2. Avoid applying a-c power operated test equipment or soldering iron without first making certain that powerline leakage current is not excessive. It is a good precaution to use an isolation transformer with all test equipment and soldering iron operated on a-c power, unless it has been determined that the equipment contains a transformer in its power supply or shows no current leakage. With all test equipment (whether transformer-operated or not), it is good practice to connect a common ground lead first from the ground of the circuit to be tested, and then to the test equipment ground.

3. Avoid application of too high a pulse from test equipment. The safest procedure is to start with a low output signal setting, and then proceed to apply the required signal levels. Be sure that the signal applied is below the rating given for the circuit under test. Relatively high current transients can occur when test equipment is connected to a circuit where low-impedance paths exist.

4. Avoid moving loose connections, disconnecting parts, inserting or removing transistors or similar components, and changing modular units while the equipment power is on or while the circuit is under test. Moving a loose connection, or any of the actions mentioned, will cause an inductive kickback. This can be prevented by being sure that all parts in the circuit are secure before starting the test or turning on the equipment power. Be sure to remove all possible capacitance charges from parts and test equipment before applying them to a modular assembly. When changing modular assemblies, be sure the equipment power is off.

DISCREPANCY TRENDS

By careful and continuous reference to the daily discrepancy reports, Work Center Registers, etc., a definite trend in discrepancies may be detected. Detection in itself is not difficult. The big problem is reducing these indications to basic causes or reasons for such trends. Sometimes they can be traced to improper maintenance procedures such as misalinement caused by maintenance personnel not adhering to the specifically outlined procedures. Perhaps the problem will be revealed by an investigation of the test equipment being used. Such an investigation may disclose improper operation of test equipment or that the error tolerances have been exceeded. At other times and especially in newer types of equipments, an equipment deficiency can be "pinned down" as the reason. If there should be an equipment deficiency, the supervisor should make sure that an Unsatisfactory Material/Condition Report (UR) is completed and forwarded so that corrective action may be taken after further investigation by the Naval Air Systems Command. No matter what the cause, analysis of the problem is required when a trend in discrepancies is noted.

ANALYZING DEFICIENCIES

In order to properly analyze any problem, the supervisor must have a thorough understanding of the operation of the equipment being maintained and the test equipments necessary to maintain it. Armed with this information and with a sincere and conscientious approach, almost any maintenance problem can be deliberately and systematically resolved in reasonable time. Most of the difficult and many of the seemingly impossible problems have been solved by careful and painstaking testing and recording of indications obtained through voltage and resistance checks, waveform comparisons, and the application of basic theories. The more difficult the problem the more exacting procedures and tests must be applied.

The major contribution to analyzing a problem is a clear and orderly thought process. The supervisor must provide this ingredient since test equipment, charts, and tables will only contribute the necessary material to be used in these thoughts.

While the supervisor is involved in analyzing these deficiencies, he may discover a better method of alinement or find a potential trouble spot in the equipment for which he may help find a solution by making known a suggestion to remedy the situation. By so doing he will be aiding in the entire program of improving productivity by saving manhours and material. This process is known as value analysis in maintenance operations (VAMO).

Value Analysis in Maintenance Operation

Value analysis in maintenance operation can be defined as a systematic and continuing evaluation of those factors affecting the efficient maintenance of a component, equipment, or system. It encompasses functional as well as engineering design standardization, and reliability as well as ease and frequency of maintenance operations. The maintenance supervisor accepts his responsibility to keep the equipment in readiness and conscientiously attempts to "keep them flying." He will not knowingly compromise the functioning of equipment under his jurisdiction even though occasionally he must ground aircraft because of insufficient time to complete a job. When an aircraft is grounded, it affects the fulfillment of the Navy's mission. Value maintenance, if objectively and actively pursued, can result in increased maintenance efficiency by saving manhours of work center time and thereby result in fewer grounded aircraft.

Through value analysis and human and design engineering, efforts are continually being made to build maintainability and reliability into all new components, equipments, and systems. However, the one missing ingredient is the knowledge of how a specific component, equipment, or system will perform under actual operating conditions and what to do to improve this performance. The maintenance supervisor is in a position to obtain firsthand information based on operating experience and to observe the degree of maintainability and reliability designed into the equipment. Accumulated data should be shared with other maintenance supervisors and forwarded through channels to NavAirSysCom.

As a Navy maintenance supervisor, you earned your rating by having the ability and intelligence to do the job. Maintenance in many respects is just as important in the overall picture as the original design. Any equipment that requires repeated routine inspection is not serving the Navy to best advantage. Such equipment presents a logistic problem which costs money. As a maintenance supervisor, such situations can often be remedied simply by sharing time saving ideas. Constructive criticism and suggestions are always helpful. A few minutes saved may seem insignificant; but if others are also able to save time by following suggested shortcuts, the Navy will be able to measure its savings in hours or days.

Consider evaluating your equipment for places where improvements can be made. There are many potential trouble spots that rate particular attention. A few examples of the kinds of questions maintenance men should ask and items they should keep in mind are listed below for future reference. This is not an all inclusive list, because new equipment and new equipment locations will always present new problems. VAMO is a continuing challenge to your ingenuity as a maintenance supervisor.

1. Controls and adjustments should be located so that they can be seen readily and reached without difficulty. Parts of an equipment should not have to be removed or disassembled for access during maintenance.
2. When replacing a component, other components should not have to be removed.
3. Connecting cables should be long enough to permit withdrawing the equipment for access to adjustments without breaking the electrical connections. In modulized equipment, a test (extension) cable should be provided, thus permitting the unit to be serviced without demounting the entire assembly.
4. Be especially careful to check for unkeyed connectors having a symmetrical pin arrangement that could be misconnected inadvertently, and also for places where the wrong connector could be inserted because of its similarity in size, etc., to the correct one.
5. Look for operations that are hazardous (either from an electrical shock or physical standpoint). More time is required to make an adjustment in a cramped physical position than when the control is located at a convenient level.
6. Quick, easily identifiable component nomenclature is always a must. Minutes of search time can be saved.

In summary, any unusually difficult operation should be analyzed for a simpler solution. Once the problem is solved share the solution with others.

Although the Navy does not have a specific, formalized program of VAMO, its value analysis principles are utilized daily. The Material Reliability Program is an excellent example of an important phase of value maintenance. This program, in part, utilizes the Unsatisfactory Material/Condition Report (UR). Operating activities are responsible for prompt submission of UR's. The maintenance supervisor should make every effort to determine the precise causes of component failures or malfunctions, particularly those involving aircraft accidents. If this cannot be done locally, priority disassembly and inspection reports or laboratory analysis reports, as appropriate, should be requested.

Every time a UR is submitted, a far-reaching program for the evaluation of faults, malfunctions, or failures of materials is started. These reports must be analyzed; statistics must be collected and correlated; and the results must be evaluated and fed back to personnel who are responsible for seeing that any needed corrective action is taken. The results of the UR programs are commendable. Changes resulting from these reports release thousands of maintenance manhours for other tasks which help to keep our aircraft in the air and even save lives by eliminating dangerous conditions.

The maintenance supervisor's contribution to the value maintenance operation should not be limited to submitting UR's. When a design deficiency, publications error, or improper supply parts or FSN's is discovered, action should be taken by one of two methods: First, request the division officer to initiate an official letter, via the chain of command, to the Naval Air Systems Command; and second ask for the assistance of a NAESU field engineer. This engineer will analyze the problem and prepare and forward a technical report to NAESU Headquarters. The report will be reviewed by NAESU and forwarded to the Naval Air Systems Command with recommendations for corrective action. The second method will sometimes bring corrective action much sooner than the first. For a detailed explanation of the UR, refer to Military Requirements for PO 3 & 2, NavPers 10056-C.

DEVELOPMENT OF INSPECTION PROCEDURES

In developing good inspection procedures, it is necessary to first establish an acceptable quality level of work, keeping in mind that safety must always come first. Next, a continuing procedure for analyzing discrepancy trends must be created, records must be kept, and followup action must be provided to stimulate improved workmanship. The crew's thinking must be influenced so as to incorporate principles of quality assurance in each step of the job. Technicians should be encouraged to help each other by doublechecking each other's work as they go along. Any job is properly accomplished by first delegating it to those who can and should be doing it; therefore, the best qualified technicians must be assigned to perform the inspection. Insure that these men have all the specifications and records needed to perform the inspections. Every man in the crew must understand that an inspection is not to fix blame or to comply with a requirement, but to save aircraft and lives and to provide the best operating equipment possible.

The morale and the physical condition of the crew are as equally important as their technical ability. If a man works beyond his physical capability, he does not take time to do each job with painstaking care. Morale, which is a product of leadership, plays a vastly important role in the maintenance program since it can so adversely affect the flight support effort. This, in turn, will deny a good safety environment regardless of the fact that the maintenance personnel are well trained. The supervisor must set a good example because people try to imitate or take for their own those qualities they admire in those they identify as their leaders. If the leaders are respected and admired as skilled, aggressive, professionals who create by their interest and actions a well-meaning attitude toward flying and safety, then the maintenance program will be praiseworthy.

Outstanding leadership assures high morale. When combined with adequate maintenance training and quality assurance, superior maintenance and flight support will result.

SPECIAL MAINTENANCE PROBLEMS

The effect of environmental conditions upon the operation of electronic and electrical equipment has greatly increased the maintenance problems of the technician. These conditions may be grouped under the major headings of altitude, temperature, and humidity. At the extremes of these conditions special maintenance and operating procedures are required. Equipments required to function at these extremes frequently fail due to the effect of decreased air density, radical temperature changes, and moisture.

Other special maintenance problems are introduced by the effects of radio noise interference. Among the types of radio noise interference discussed in the following paragraphs are atmospheric interference, effects of rotating and switching devices, effects of nonlinear circuit elements, and interference from a-c power sources. Also discussed are methods of suppressing radio noise interference.

HIGH ALTITUDE

As the ceiling for aircraft on extended flights has been raised higher and higher, many new types of operating and maintenance problems have developed. Some of the various types of equipment involved are generators, voltage regulators, electric motors, and solenoids. Electric brushes on generators, inverters, electric motors, and other rotating electrical machinery wear away very rapidly at high altitude. Special brushes have been developed that have longer life at high altitude. Thus, it is advisable to use the proper type brushes and to check them more frequently when high altitude flying is being performed.

While most switches will break a circuit safely at sea level, their contacts may burn and in some cases even melt at high altitude. It has been found that double-break contact switches somewhat alleviate this fault. Since electric and electronic systems use specially designed switches for high altitude operation, it is necessary to take special precautions to insure that the proper type is used by personnel making a replacement.

Other items that often fail during high altitude flights are electrical plugs and receptacles. A voltage breakdown occurs between the pins and shell along the surface of the insulating material. The result is a burned plug. This happens because the breakdown voltage is less at high altitude. For example, the breakdown voltage for a 1/4-inch airgap is about 3.7 times greater at sea level than at 40,000 feet.

This condition may be overcome by sealing the connector with a potting compound. This reduces the probability of arc-over between pins, or between pins and the shell of the electric connector since the dielectric characteristics of the connector are improved. This sealing compound will also protect the connectors from corrosion or contamination by excluding metallic particles, moisture, and aircraft liquids.

Pressurization

Airborne electronic equipment used at high altitudes is usually pressurized for the following reasons.

1. To prevent high-voltage arcing and resultant wear on brushes and relay contacts.
2. To prevent RF voltage breakdown in waveguides.
3. To eliminate the problems of condensation and corrosion in the equipment which result from "breathing."

Pressurized equipments are sealed with gaskets to make an airtight and moistureproof seal. Pressurization can be accomplished by using a combination dehydrator-hand pump. Some equipments have an electric compressor-dehumidifier built in.

The hand pump is used to pressurize some equipments with 18 to 20 psi absolute or 3 to 5 psi gage. Compressors that are installed in the aircraft with equipment such as radar are used to pressurize various units of the system with 30 to 34 psi absolute at all altitudes.

HUMIDITY

Continuous damp, warm air causes condensation of atmospheric moisture within equipment unless units are hermetically sealed or the interiors are maintanined at a temperature higher than surrounding atmospheric temperatures. Condensed moisture forms electrical leakage paths and causes corrosion. These climatic conditions also promote rapid fungus growth which in itself has a corrosive effect on materials, such as wire, switch contacts, and other metal parts.

Humidity is a term describing the amount of water vapor in the air. It is usually expressed as a percentage of the total amount of water the air can hold at a given temperature. Thus, 50 percent relative humidity means the air contains one-half the total water it can hold, and 100 percent means it contains all it is capable of holding. Air can hold more water as its temperature increases. In tropical areas the humidity varies between 60 and 100 percent.

High humidity accounts for the condensation of moisture, or sweating, on various parts of electronic equipments when they undergo temperature changes. Condensed moisture on insulating materials reduces their insulating qualities and results in arc-overs and shorts between terminals. The water vapor also penetrates into the body of insulation, is absorbed, and causes similar effects. High humidity also causes corrosion of metals. Other sources of moisture which cause deterioration include fog, salt spray, and rain.

TEMPERATURE

In general, equipment may encounter extreme temperatures, ranging from minus 65° F to a maximum of 135° F, under various climatic conditions of high humidity, fog, rain, salt spray, salt air, cold, insects, fungi, and dust. High temperature and moisture vapor cause rapid corrosion. Fungus and bacterial growths, which thrive in warm temperatures, produce acids and other products which speed corrosion, etching of surfaces, and oxidation.

This interferes with the operation of moving parts, screws, and so forth, and causes dust between terminals, capacitor plates, and other parts, which produces noise, loss in sensitivity, and arc-overs.

Variations of temperature cause moisture to be breathed through any small cracks, pinholes, or vents in the equipment. As the temperature rises, the air inside a piece of equipment expands and it is expelled, inpart, through the openings and vents. When the temperature falls, the air inside the equipment contracts and outside air is admitted through all openings and vents. The moisture which is breathed destroys the insulating qualities of dielectrics and corrodes metals.

FUNGUS

Fungus is a form of plant life which feeds on materials of vegetable and animal origin including paper, cotton, and so forth, and such things as dead insects and other fungi. These may be spread by wind, dust, dirt, and insects, such as ants, flies, and mites. Growth may take place on materials other than those of organic origin if a spot of dust or other nutrient substance is present.

Fungus growth causes decay, accelerates the deterioration of insulating materials, and short circuits items such as relays, jacks, and keys. The inclusion of a fungicidal compound in the manufacture of the equipment retards the growth of these fungi.

Most new equipment is given a climatic deterioration prevention treatment which provides a reasonable degree of protection against fungus growth, moisture, corrosion, salt spray, insects, cold, desert heat, and so forth. The treatment involves the use of a lacquer or varnish coating material applied with a spray gun or brush.

RADIO NOISE INTERFERENCE

Radio noise interference is a problem of first importance to maintenance personnel. The problem has increased in proportion to the complexity of both the electric system and the electronic equipment. Almost every component of the aircraft is a possible source of radio interference, which is one of the main factors in preventing the operation of receivers at full sensitivity. All personnel concerned should be familiar with the problem of radio noise and how to eliminate it.

The overall effect of radio interference of any kind is to impair or deteriorate the performance and reliability of radio and electronic sets or systems. The interference may act directly by actual deterioration of the equipment response, or indirectly by wearing down the patience and tolerance of the human operator. Either way, the result is the same, since combat efficiency is materially reduced.

The technician should know the following:

1. What radio interference is.
2. Where the interference originates.
3. How it gets into equipment.
4. How to identify it.
5. How to suppress it at its source.
6. How to segregate its path of entry into a receiver.
7. How to prevent its entry into a receiver.
8. What considerations enter into the design of an interference-free equipment.
9. How to position and install electrical and electronic devices.

This information is presented in detail in the publication, Installation and Maintenance Practices for Reduction of Radio Interference in Aircraft Electronics, NA 16-1-521. Some of the more important of this information is presented briefly in the following pages.

Atmospheric and Precipitation Static

Atmospheric static is a burst of RF energy caused by electrical discharges in the atmosphere. Although the frequency spectrum of atmospheric static is very wide, only frequencies in and below the high frequency band propagate far enough to be very troublesome at long distances from the electrical disturbance. Therefore, UHF and VHF receivers are seldom troubled by atmospheric static. Reduction of such static is obtained by use of frequency modulation, directional antennas, and noise limiter circuits. Frequency modulation is not used extensively in aircraft radio communications because of the bandwidth requirements.

Precipitation static is caused by the development of large static charges on the aircraft when it is flown through snow, rain, ice crystals, or dust clouds. An aircraft can build up a charge of several hundred thousand volts in a few seconds. The resulting high voltage gradients at extremities and sharp points exceed the breakdown strength of air and cause noisy corona discharges.

The conventional radio antenna, which must stand away from the body of the aircraft to be of effective height, is exposed to high electric fields. This means that corona discharges occur first in the antenna system, the very place that is most sensitive to noise. Precipitation static is reduced by using a completely insulated antenna system—that is, by using wire with high voltage insulation instead of bare wire, and by insulating all connections and supports for the antenna wire.

Precipitation static is reduced also by eliminating all sharp metal projections from the aircraft and by installing dischargers, which quietly discharge accumulated static charges at a high rate. A discharger consists of silver-impregnated cotton wicking encased in a flexible plastic tube with an aluminum mounting lug. The many fine high resistance fibers provide a multitude of discharge points. The resulting discharges are quiet unless the current is very high. For detailed information on precipitation static refer to NA 16-1-518, Installation and Maintenance Instructions, Anti-Precipitation Static System.

The effect of precipitation static is a loud hissing or frying noise from the speaker or headset of radio equipment and interference (grass) on the picture tube of visual output receivers. As a technician you should be concerned with precipitation static since it is produced only when the aircraft is flying. Also, the preventive measures that are taken are among the primary responsibilities of your rating. You should be aware of its characteristics for there is the probability that you will have to correct for radio interference that is caused by precipitation static.

INHERENT INTERFERENCE

Interference is inherent in the design of receiving equipments. This factor, brought about by the random motion of free electrons in a conductor, causes small potential difference to be developed across the terminals of the conductor. This action, called thermal agitation, is a common source of background noise. Inherent interference is of great concern in radar operation.

Vacuum tubes act as a source of noise because of the nature of their operation. They cause a noise commonly called "shot" effect. Shot effect is created by electrons being emitted from the cathode in a random way so that any current resulting from such emission has a random variation.

Components that transfer energy in the form of heat are interference generators. However, interference of this nature is unavoidable. Proper selection of components will reduce this interference to accepted standards.

Manmade Radio Noise

Manmade radio noise is caused by electrical transients which occur during the operation of electrical or electronic equipment. In brief, manmade radio noise will be generated whenever an electrical circuit is open or closed abruptly, such as by a relay, commutator, or other make and break devices. A similar condition exists when large amounts of current are periodically and abruptly started and stopped, as in radar circuits. An electric spark is a generator of electrical disturbances which appear to cover the entire radiofrequency spectrum.

ROTATING ELECTRIC MACHINES.—The types of interfering voltages generated by d-c machines are:

1. Switching transients as the brush moves from one commutator bar to another. This is usually called commutation interference.
2. Random transients caused by varying contact between brush and commutator. This is usually called sliding contact interference.
3. Audiofrequency hum (commutator ripple).
4. Radiofrequency and static charges built up on the shaft and rotor assembly.

Direct-current motors used in aircraft systems are of three general types: series wound, shunt wound, and permanent magnet field. The field windings of both series- and shunt-wound motors afford some "padding" or filter action against transient voltages generated by the brushes. The permanent-magnet motor's lack of such inherent filtering makes it a very common source of interference.

It must be emphasized that the size of a d-c motor has little effect upon its interference generating characteristics. The smallest motor aboard may well be the worse offender.

The output of an ideal a-c generator is a pure sine wave. A pure sine wave voltage is incapable of producing interference except at its basic frequency. However the ideal waveform is difficult to produce, especially in small machines.

Practically all types of a-c power generators currently used in naval aircraft have proved to be potential sources of interference at other than the output power frequencies. This interference is produced in the following forms:

1. Harmonics of the power frequency caused by poor waveform.
2. Commutation interference (series-wound motors).
3. Sliding contact interferences (a-c generators and series-wound motors).

It should be noted that a-c motors that do not use brushes are almost never sources of interference.

SWITCHING DEVICES.—Abrupt changes in electric circuits occur when switching takes place. Such changes are accompanied by transients capable of interfering with the operation of radio and electronic systems. The simple manual switch is of little consequence as a source of interference because its frequency of operation is usually not great. Example of frequently operated switching devices capable of appreciable or serious interference are relays, vibrators, and thyratrons.

Since relays are used almost exclusively to control large amounts of power with relatively small amounts of power, they are always potential interference sources. This is especially true when they are used to control inductive circuits. Relay actuating circuits should not be overlooked as interference sources, because even though the actuating currents are small, the inductances of the actuating coils are usually quite high. It is not unusual for the control circuit of a relay to produce more interference than the circuit which it controls.

Induction vibrators are essentially double-pole, double-throw relays which operate at a constant rate. As in any induction type switch or relay, there are two sources of switching transients: the inductive field contacts and the switching contacts. The output waveform of the vibrator is essentially rectangular at some audiofrequency. Its harmonic content is high and filtering is difficult.

Because of its interfering capabilities, the vibrator is seldom used as a radio power source in naval aircraft except for certain commercially available radio equipments found in small auxiliary aircraft. (Vibrators are used as d-c choppers in some servosystems.)

Thyratrons are gas filled, grid controlled, electronic switching tubes which are used for many purposes. Among the most common uses are keyer tubes in radar modulators, rectifiers in regulated power supplies, rectifiers in servosystems, and relay applications. The current flow in a thyratron is either all on or all off; there is no in-between. Since the time required to turn a thyratron on is only a few microseconds or less, current waveforms in thyratron circuits always have steep fronts. As a result, they are rich in radio interference energy (transients).

NONLINEAR CIRCUIT ELEMENTS.—A conductor or semiconductor whose resistance or impedance varies with the voltage applied across it is a nonlinear element. Nonlinear elements that may cause radio interference in aircraft, in the order of their frequence, are overdriven vacuum tubes, oxidized or corroded joints, cold solder joints, and unsound welds. In the presence of strong signals a nonlinear element behaves as a detector or mixer, producing harmonics and sum and difference frequencies from signals applied to it.

A-C POWER SOURCES.—Radio interference of a broadband nature is produced by a-c power sources. In a-c powered equipments, a-c hum may appear at the power frequency or at the rectification ripple frequency. The ripple frequency of a full-wave rectifier is twice the power frequency times the number of phases. Normally, aircraft systems utilize only single- and 3-phase sources at 400 Hz. Full-wave rectification of single-phase, 400-Hz power gives a ripple frequency of 800 Hz; a 3-phase source yields 2,400 Hz. This ripple can produce interference varying from annoyance to complete unreliability of equipment, depending on its severity and its coupling to susceptible elements.

SUPPRESSION METHODS.—Suppression of radio noise has advanced to the point where the proper application of available techniques will insure that receiving equipment installed in aircraft will operate at optimum efficiency. Four types of suppression techniques are involved.

Isolation is the easiest and most practical method of radio noise suppression and revolves around the possibility of separating the source of radio noise from the input circuits of the receiving equipments affected. As every manmade radio noise source can be considered a small transmitter, it is obvious that the radio noise source and leads carrying radio noise energy should be kept as far away from receiver antennas or lead-ins as possible.

In many cases, the radio noise in a receiver may be entirely eliminated simply by moving the antenna lead-in wire just a few inches away from the source of radio noise. The value of sufficient separation between sources of radio noise and receiver input circuits is not apt to be overemphasized. The isolation method of radio noise suppression is very popular as it has the advantages of not requiring any additional material or adding any additional weight.

Bonding is a very important means of radio noise control. It provides grounding of all insulated conducting objects on the exterior of the aircraft. When conducting objects are not grounded, flight through precipitation causes high voltage charges to build up on those objects. Repeatedly, the voltage gets high enough to spark over to an adjacent ground member or the object discharges to the surrounding air by corona conduction. Either mode of discharge causes considerable radio noise.

Other important functions of bonding are:

1. To protect the aircraft and personnel from lightning discharges by equalization of potentials which might cause arcs and sparks in the aircraft structure.
2. To provide a homogeneous counterpoise for radio transmission and reception.
3. To provide power current return paths.
4. To provide a short path bypassing RF noise.

All electronic equipments should be ground to the aircraft structure. This is done by using short bond straps or sheets of high conductivity (copper or aluminum) metal where it is impossible to use a short bond strap. No bond strap should be more than 4 inches in length.

Shielding is one of the most effective methods of suppressing radio noise. The primary object in shielding is to electrically "bottle up" the radiofrequency noise energy. In practical application, this means that the radio noise energy must be kept flowing along the inner surface of the shield. The use of good shielding is particularly effective in situations where filters cannot be used. A good example of this is where radio noise energy radiates from a radio noise source and the radiated energy is picked up by the various circuits that eventually connect to the receiver input circuits. It is obvious that it would be impractical to filter a number of leads or units that are influenced by the radio noise energy; hence, the application of effective shielding at the noise source itself is advisable for it will eliminate the radiated portion of the radio noise energy by confining it within the shield at its source.

Radio interference as radiated or conducted from a source may be of a single frequency or may cover an extended band of frequencies. When bonding, shielding, or isolation of the source proves ineffective as a means of reducing radio interference, it becomes necessary to employ filters to accomplish this reduction. A filter is defined as a selective network which transmits freely electric waves having frequencies within one or more frequency bands and which attenuates substantially electric waves having other frequencies.

The size of a filter may vary widely, depending on the voltage and current requirements as well as the degree of attenuation desired. Filters are usually incorporated in equipment known to generate radio interference, but these filters are often inadequate, and in many cases it is necessary to add filters external to these equipments. This is especially true if the source of interference is coupling interference to paths of entry to a receiver other than the powerline.

The types of filters used in the reduction of radio interference vary with the application, but each of the general filter types may be found to be particularly adaptable to some specific situation. Most of the electrical devices connected to powerlines require, for their operation, features which are conductive to the generation of radio interference.

The interference generated by these devices, unless properly attentuated, is impressed upon the power lines and conducted to the receivers. It may also be conducted into the receivers by inductive coupling to other wiring associated with the receivers. This interference, unless attenuated by means of filters, is then transmitted along these powerlines, entering the receivers at the powerline input; or this interference may be radiated somewhere along the powerlines and enter the receiver by means of the antenna system.

Filters are of four kinds and are identified as follows:

1. The low pass filter, which introduces negligible attenuation at all frequencies below a certain frequency, called the cutoff frequency, and relatively high attenuation at all higher frequencies.
2. The high pass filter, which introduces negligible attenuation at all frequencies above a certain frequency, called the cutoff frequency, and relatively high attenuation at all lower frequencies.
3. The bandpass filter, which introduces negligible attenuation at all frequencies within the range between two frequencies, and relatively high attenuation at all other frequencies.

4. The band elimination filter, which introduces negligible attenuation at all frequencies outside a certain range, and relatively high attenuation at all frequencies inside that range.

For information that covers the theory of operation of these filters, refer to chapter 10 of Basic Electronics, NavPers 10087-C, Vol. 1.

The normal characteristics of a filter are obtained only when the filter is properly terminated in its characteristic impedance.

A wave trap is a filter or network especially designed to reject certain frequencies, or bands of frequencies. Networks of this type may be installed at the antenna of the transmitter or receiver in order to attenuate frequencies outside of the assigned frequency range of the equipment. All such networks must have low insertion loss, or attenuation, for the pass frequencies. In the design and construction of wave traps, the insertion loss is usually below 2 db.

There are two basic circuit configurations for filter networks, the pi-section and the T-section. Each may be broken down into half section which have an inverted L-shape and are known as L-section filters. If a number of pi- or T-sections are connected in series to form a filter, the resultant network is called a ladder network. Any of the above circuit configurations may be used for radio interference elimination.

In general, the use of simple capacitor filters is to be preferred over that of the more complicated network filters in cases where this type of filter provides the required degree of radio interference attenuation. In this method, the radio noise energy passes through the capacitor to ground. This short-circuiting effect is due to the fact that the capacitor offers a very low impedance path across the noise source terminals.

A given capacitor is effective in bypassing only a limited range of radio interference frequencies because of its internal inductance and the inductance of the connecting leads. The inductance of the capacitor depends upon its capacity, the material of which it is fabricated, and the length of the connecting leads.

The capacitor leads are the major contributors to the inductance of capacitors. Therefore, small mica capacitors, with short leads are more effective as filters at high frequencies than large paper capacitors with normally long leads. Electrolytic capacitors should never be used as filters because of the danger of dielectric breakdown.

The popularity of the capacitor type filter is due to the fact that the current used for operation of the radio noise source does not have to pass through the filter. The only energy passing through the filter is the radio noise energy. The most important limiting factor in the choice of a capacitor type filter is the breakdown voltage rating of the capacitor. It must be well above the voltage used to operate the source of radio noise to be filtered. For example, where a 24-volt source of noise is to be bypassed with a capacitor, the working voltage of the capacitor should be at least 50 volts.

CHAPTER 5

AVIONICS SUPPORT EQUIPMENT

For effective operation of an avionics system, it is imperative that the electronic equipments operate at maximum effectiveness within the designed limits. To accomplish this, the technician must employ the best maintenance techniques and he must utilize the test equipment to the utmost.

The following discussion on the operation and circuitry of various test equipments is designed to aid the AT in furthering his knowledge of these test equipments and their use in effective maintenance of avionics equipments. The technician should bear in mind that this discussion is not a substitute for the test equipment's Operation Instruction or Service Instruction Manual, which should be consulted before operating any type of test equipment.

RF SIGNAL GENERATOR

Signal Generator AN/USM-44A is the nomenclature assigned to the TS-5104/U signal generator and its assessories. This equipment is complete, self-contained, and transportable. It includes, in addition to the signal generator itself, the following accessories: A watertight transit case, power and RF cables, connector adapters, and an output fuse holder for protection of the RF output attenuator.

PURPOSE

The AN/USM-44A is a general purpose test equipment capable of furnishing accurately adjustable radiofrequency signals from 10 to 420 megahertz. The instrument may be amplitude modulated by internally generated sine waves, or by externally applied sine waves or pulses. The set includes a built-in crystal controlled heterodyne calibrator which permits the operator to adjust the output frequency to a high degree of accuracy. The instrument features direct reading meters and controls throughout.

OPERATING PROCEDURES

The Operating Instruction Manual for the AN/USM-44A outlines step by step procedures for operating the equipment in each of the following modes of operation:

1. Continuous wave.
2. Internal sine wave modulation.
3. External sine wave modulation.
4. External pulse modulation.

The manual also furnishes the operator with instructions for using the frequency calibrator and contains a section on signal generator loading considerations.

BLOCK DIAGRAM ANALYSIS

The signal generating circuits are shown in block diagram form in figure 5-1. The unit contains a regulated power supply which is not shown in the block diagram.

The RF oscillator generates a variable frequency RF signal which is fed through a buffer and power amplifier to the output circuit. The oscillator is of the Colpitts type, and is carefully designed for high stability.

The buffer isolates the oscillator from the power amplifier and minimizes interaction between the two circuits.

The RF power amplifiers receive both the RF and the modulation signals and amplify the RF energy for application to the output attenuator. The RF amplifier receives variable bias from the modulator which permits adjustment of the power level fed to the output attenuator.

The power monitor samples the RF energy fed to the output attenuator and indicates the power and voltage level on a front panel meter. The output attenuator obtains the monitored RF energy from the power amplifier, applies the selected degree of attenuation, and conducts the energy to the front panel output jack.

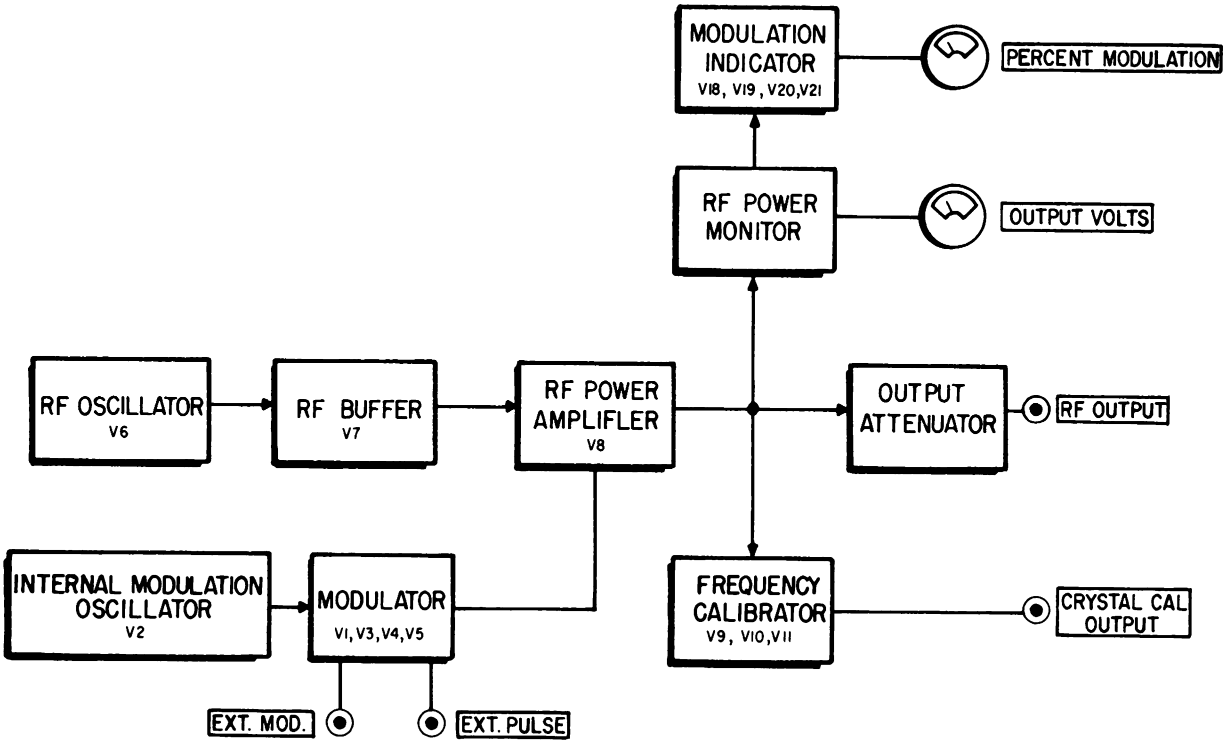


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Figure 5-1.—Signal circuit block diagram.

The beat frequency calibrator generates harmonics of the 5-MHz signal obtained from the crystal, as well as harmonics of the 1-MHz signal obtained from a tuned circuit and mixes these harmonics with the RF output signal coupled from the RF amplifier. The resultant beat frequency signal is amplified and fed to the front panel headphone jack.

The internal modulation oscillator generates either a 400- or 1,000- Hz sine wave for application to the modulator. The modulator receives all modulation signals for application to the RF power amplifier and also supplies variable bias to the amplifier for control of the RF output power level.

The modulation measuring circuits receive detected modulation from the RF power monitor, amplify and rectify it, and indicate the modulation percentage directly on a front panel meter.

RF Oscillator

The RF oscillator generates a sine wave signal from 10 to 420 MHz in 5 frequency bands. The Colpitts oscillator circuit is tuned by a precision split stator capacitor and 5 separate RF transformers. The tuned circuit components are specially constructed for high stability.

RF Buffer

A loosely coupled secondary winding on each of the RF oscillator coils couples RF energy from the oscillator to the buffer stage. The buffer stage is connected as an untuned grounded grid amplifier and serves to isolate the oscillator circuit from the effects of the modulation signal at the cathode of the power amplifier circuit. The use of the buffer reduces incidental frequency modulation to an extremely small value.

RF Power Amplifier

The RF power amplifier amplifies the energy received from the buffer for application to the RF output attenuator. The circuit is connected as a grounded grid, cathode modulated amplifier. The plate circuit is tuned in the same manner as the oscillator, with a similar split stator capacitor and five coils. The amplifier capacitor is provided with a mechanical linkage, controlled from the front panel, that allows the rotor plates to be shifted from their normal tracking position. This control allows the amplifier tuning to be separately adjusted for maximum output at all frequencies.

Output Attenuator and RF Power Monitor

A piston attenuator is used to control the power obtained from the RF power amplifier. The housing for the attenuator projects through the rear of the RF generator housing and terminates, open ended, close to the RF amplifier plate circuit inductor. The nonresonant, single turn pickup loop at the end of the attenuator probe couples energy to an impedance matching network, then through a section of double shielded coaxial cable to the RF OUTPUT jack. The probe has a movable sleeve in the probe body which allows minor adjustments of the internal impedance of the generator so that a minimum standing wave ratio is obtained when the output jack is terminated in a 50-ohm resistive load.

The RF power level which is fed to the attenuator is sampled and continuously monitored. This power level is indicated in both volts and decibels over a limited range, on the front panel power level meter. A calibration mark on the meter establishes a predetermined amount of power fed into the attenuator for direct reading of the output attenuator dial calibrations.

Frequency Calibrator

The frequency calibrator consists of a crystal controlled oscillator, a mixer, and a 75-db resistance coupled amplifier. The accuracy of the crystal oscillator allows the frequency dial calibration to be set very accurately at the checkpoints. The calibrator is turned on as long as the signal generator is turned on.

Modulator Section

The purpose of the modulator section is threefold: To generate 400-Hz and 1,000-Hz sine waves for internal modulation of the generator; to amplify all modulation signals for application to the RF power amplifier; and to control the power level obtained from the RF amplifier for all types of operation by varying the bias on the RF amplifier. The modulator consists of a Wein bridge type oscillator, a limiter, amplifiers, a cathode follower output stage, and an output level control tube.

Modulation Measuring Circuits

The modulation measuring circuits indicate the degree of sine wave modulation of the RF output signal directly in percentage between 0 and 100 to an accuracy of 10 percent or better. These circuits consist of a stabilized wideband amplifier and a bridge type meter circuit. The circuit amplifies the detected modulation from the RF power monitor circuit, rectifies it, and applies the resultant d-c voltage to the meter bridge. Being a peak reading instrument, the meter indicates the modulation percentage of most waveforms that are applied to the EXT MOD jack. The meter is calibrated to indicate the percent modulation of a given amount of RF carrier power.

Power Supply

The power supply for the signal generator consists of two electronically regulated high voltage supplies, one providing -165v d.c., the other providing +225v d.c. Each regulator is supplied from a full wave bridge type selenium rectifier. The power transformer supplies a-c heater voltage for all tubes except the RF oscillator and power amplifier. These tubes receive constant heater voltage from a separate circuit.

DIGITAL READOUT ELECTRONIC COUNTER AN/USM-207

The AN/USM-207 is a portable, solid-state electronic counter for precisely measuring and displaying on an nine-digit numerical readout the frequency and period of a cyclic electrical signal, the frequency ratio of two signals, the time interval between two points on the same or different signals, and the total number of electrical impulses (totalizing). The counter also provides the following types of output signals:

1. Standard signals from 0.1 Hz to 10 MHz in decade steps derived from a 1-MHz frequency standard, frequency dividers, and a frequency multiplier.

2. Input signals divided in frequency by factors from 10 to 10^8 by a frequency divider.

3. Digital data of the measurement in four-line binary-coded-decimal form with decimal point and control signals for operation of printers, data recorders, or control devices.

4. A 1-MHz output from a frequency standard.

GENERAL DESCRIPTION OF AN/USM-207

The AN/USM-207 (fig. 5-2) consists of a major counter assembly, two plug-in assemblies which install in recesses on the front and rear panel, and a group of accessory cables and connectors stored in the detachable front cover.

Digital Readout Electronic Counter CP-814/USM-207

The major assembly Digital Readout Electronic Counter CP-814/USM-207 contains the input amplifiers, gate control, display, reset and transfer control, frequency multipliers, time base dividers, decade and readout boards, numerical display tubes, decimal point and units indicators, power supply and regulator, and controls associated with these circuits.

Radiofrequency Oscillator 0-1267/USM-207

The Radiofrequency Oscillator 0-1267/USM-207 plug-in assembly develops a 1-MHz signal and includes its own power supply. The oscillator includes the 1-MHz output receptable which may be used as a source of that frequency when the oscillator is connected to a-c power through the basic counter or when connected to the power line independently of the counter. The counter may be operated without the oscillator in totalizing, in scaling the input signal, in time interval with external clock, and in frequency ratio

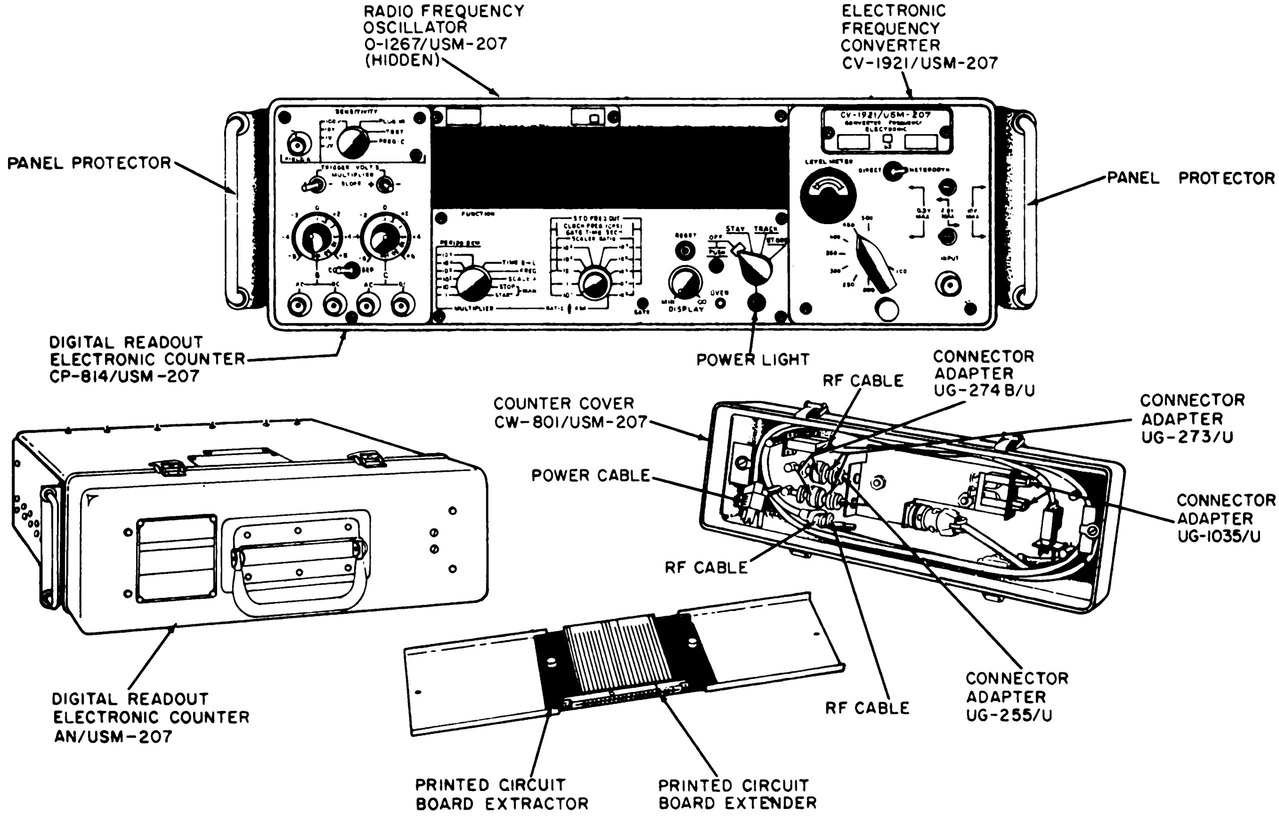
RADIO FREQUENCY OSCILLATOR O-1267/USM-207 (HIDDEN)
ELECTRONIC FREQUENCY CONVERTER CV-1921/USM-207
PANEL PROTECTOR
PANEL PROTECTOR
DIGITAL READOUT ELECTRONIC COUNTER CP-814/USM-207
POWER LIGHT
RF CABLE
CONNECTOR ADAPTER UG-274 B/U
COUNTER COVER CW-801/USM-207
CONNECTOR ADAPTER UG-273/U
POWER CABLE
CONNECTOR ADAPTER UG-1035/U
RF CABLE
DIGITAL READOUT ELECTRONIC COUNTER AN/USM-207
RF CABLE
CONNECTOR ADAPTER UG-255/U
PRINTED CIRCUIT BOARD EXTRACTOR
PRINTED CIRCUIT BOARD EXTENDER

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Figure 5-2.—Digital Readout Electronic Counter AN/USM-207.

measurements. For other measurements the counter does not require the oscillator when a separate external 100-kHz or 1-MHz signal is connected. In either of these two situations, the oscillator may be left in the counter or removed. The oscillator plugs into the right rear of the counter.

Electronic Frequency Converter CV-1921/USM-207

The Electronic Frequency Converter CV-1921/USM-207 plug-in assembly permits measurement of frequencies up to 500 MHz using the heterodyne principle. The unit consists of the broadband amplifier, mixer, multiplier, and controls and indicators associated with these circuits. When measurements other than heterodyne frequency measurements are made, the converter is not required, but need not be removed. The converter also permits the measurement of signals from 35 MHz to 100 MHz with a greater sensitivity than available with the basic counter. The converter plugs into the right front of the counter.

FUNCTIONAL DESCRIPTION

Figure 5-3 is the overall functional block diagram of the counter. Two types of information are required to make a measurement—a count signal and a gate control signal. These two signals may be generated within the instrument or they may be supplied from external sources. The type of measurement the counter will make depends upon the relationship of these two signals. In any function the instrument counts the count signal for a period of time determined by the control signal. Routing of these signals within the instrument is accomplished by logic circuit and controlled by means of the front panel controls.

The radiofrequency oscillator (O-1267/USM-207) generates a signal of precise frequency for use throughout the counter or to provide a precise 1-MHz signal for use outside the equipment.

The electronic frequency converter accepts radiofrequencies between 100 MHz and 500 MHz and converts them to radiofrequencies between 5 MHz and 100 MHz for measurement by the basic counter.

The A amplifier amplifies the A input signal or the output of the converter for use throughout the counter.

The B amplifier amplifies and shapes the B input signal for use throughout the counter.

The C amplifier amplifies and shapes the C input signal for use throughout the counter.

The 10-MHz and 1-MHz multiplier multiplies the frequency and shapes the signal generated by the radiofrequency oscillator. It also provides precise timing signals to the various functional sections of the basic counter and to the frequency converter.

The scaler consists of a series of decade dividers and gating systems which provide divided standard frequencies and controls signals, depending on the type of measurement the instrument is making.

The gate control generates the gate control signal. This signal determines the length of time that the count decades will count the count signal.

The count control provides the proper count signal to the count decades, as selected by the setting of the front panel switches.

The cycle control produces all signals necessary to display the measurement results on the readout and to recycle the counter.

The count decades count the count signal when permitted to do so by the gate control. The result of their counting becomes the final reading displayed by the readout at the end of each measurement.

The readout receives binary-coded-decimal (BCD) data from the count decades, decodes this data into decimal form, and drives the readout indicator tubes. The readout also contains memory circuits which function when the counter is operated in the STORE mode.

The power supply furnishes all d-c power required by the basic instrument and the converters and consists of seven d-c supplies. Five of these supplies (+18 volt, +12 volt, +6 volt, -6 volt, and -12 volt) are regulated and two (+180 volt and +45 volt) are unregulated.

TACAN BEACON SIMULATOR

This equipment is a test set designed to produce simulated TACAN surface beacon signals and other signals for testing airborne TACAN equipment.

The TACAN Beacon Simulator, Radio Test Set AN/ARM-22, can simulate fixed or variable ranges from 0 to 198 miles, all bearings from 0° to 360°, air-to-air function, and tone signals for the operation of the identity circuits of the airborne receiver-transmitter. The test set can transmit these simulated signals to the

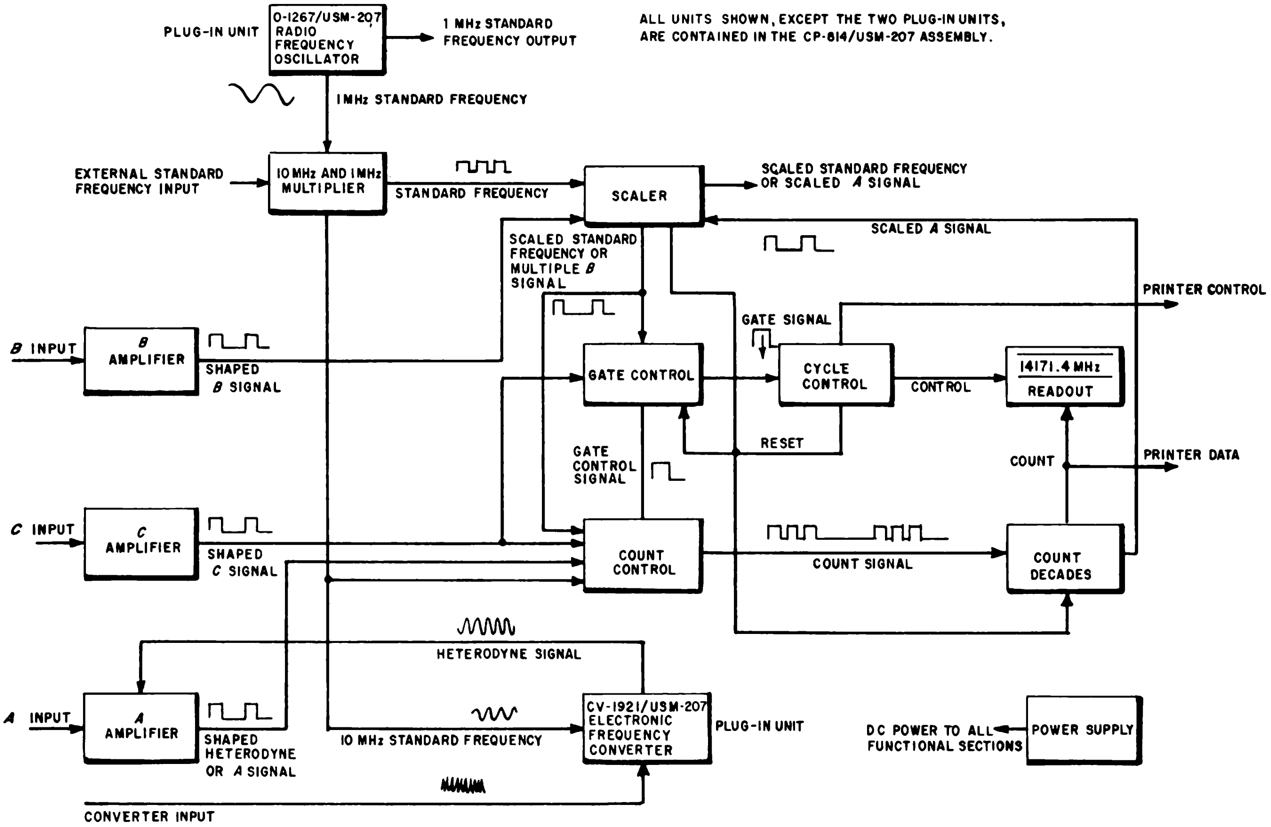
PLUG-IN UNIT
O-1267/USM-207 RADIO FREQUENCY OSCILLATOR
1 MHz STANDARD FREQUENCY OUTPUT
ALL UNITS SHOWN, EXCEPT THE TWO PLUG-IN UNITS, ARE CONTAINED IN THE CP-814/USM-207 ASSEMBLY.
1 MHz STANDARD FREQUENCY
EXTERNAL STANDARD FREQUENCY INPUT
10 MHz AND 1 MHz MULTIPLIER
STANDARD FREQUENCY
SCALER
SCALED STANDARD FREQUENCY OR SCALED A SIGNAL
SCALED A SIGNAL
SCALED STANDARD FREQUENCY OR MULTIPLE B SIGNAL
PRINTER CONTROL
GATE SIGNAL
B INPUT
B AMPLIFIER
SHAPED B SIGNAL
GATE CONTROL
CYCLE CONTROL
CONTROL
14171.4 MHz
READOUT
RESET
GATE CONTROL SIGNAL
COUNT
PRINTER DATA
C INPUT
C AMPLIFIER
SHAPED C SIGNAL
COUNT CONTROL
COUNT SIGNAL
COUNT DECADES
HETERODYNE SIGNAL
A INPUT
A AMPLIFIER
SHAPED HETERODYNE OR A SIGNAL
10 MHz STANDARD FREQUENCY
CV-1921/USM-207 ELECTRONIC FREQUENCY CONVERTER
PLUG-IN UNIT
DC POWER TO ALL FUNCTIONAL SECTIONS
POWER SUPPLY
CONVERTER INPUT

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Figure 5-3.—Digital Readout Electronic Counter AN/USM-207, overall functional block diagram.

equipment being tested on any one of 126 preselected channels.

When used in conjunction with Test Set Indicator AN/ARM-31, the capabilities of the equipment are increased. The simulator information sent to, and then processed by, the equipment being tested may be displayed by the test set indicator. This enables the operator to test individual components of the aircraft TACAN equipment.

The AN/ARM-22 is usable at shore station maintenance facilities as well as aboard ship.

OPERATING PROCEDURES

The Operation Instruction Manual, NavAir 16-30ARM-22-501, is supplied for use with Radio Test Set AN/ARM-22. Instructions contained in this manual should be followed when operating the test set.

In addition to the step by step operating instructions, the manual contains operating checks and adjustments, operating precautions, listings of equipment furnished and equipment needed, and general information on the AN/ARM-22.

THEORY OF OPERATION

This section covers the theory of operation for Radio Test Set AN/ARM-22. A discussion of the TACAN system and surface beacon is included to familiarize the maintenance technician with the overall system tie-in.

TACAN System

The test set provides simulated TACAN surface beacon facilities for conducting bench checks of airborne TACAN receiver-transmitters. These tests are carried out under closed circuit conditions and provide artificial range, azimuth, and tone identify information for performance evaluation of the associated circuitry in the airborne equipment.

The surface beacon provides a composite envelope which consists entirely of pulse pairs that are generated at the rate of 3,600 pairs per second. Of these pulse pairs, 900 are repetitive reference groups. The remaining 2,700 pulse pairs constitute fill-in "squitter" (randomly occurring pulses) and reply pulse pairs, used for distance information. In conjunction with the 900 reference group pulse pairs, all pulse pairs are amplitude modulated by the beacon antenna rotation, at 15 and 135 Hz, for azimuth information.

To obtain distance information, the aircraft transmitter radiates a series of interrogation pulse pairs. These pulse pairs are picked up by the receiver portion of the surface beacon and, following a fixed delay of 50 μsec, retransmitted to the aircraft as an identical series of reply pulse pairs. The time interval between interrogation signal transmission, beacon reply, and pulse reception by the receiver portion of the aircraft equipment, is a function of the distance between the aircraft and the beacon. This interval is directly translated into terms of distance and is displayed on a suitable indicator in the aircraft. Other aircraft, which use the same surface beacon, employ the same operating frequency. However, the pulse repetition frequency (PRF) of the interrogating signal has random pulse spacing and is different for each aircraft. The beacon transmitter replies with a PRF identical to those transmitted and the aircraft receiver circuits ignore PRF's which are not identical to those originally transmitted. This method permits the simultaneous use of the same beacon by as many as 100 aircraft.

Azimuth information is transmitted by amplitude modulation at 15 and 135 Hz. It is necessary, therefore, to insure that in the absence of sufficient interrogation, the pulse output is maintained at an average of 2,700 pulse pairs per second plus the reference pulse groups which preserve the complete modulation envelope. This is done by supplementing the interrogating pulse pairs by sufficient squitter pulse pairs. When interrogation pulse pairs are received, a sufficient number of squitter pulses will be eliminated to keep the rate constant at 2,700 pulse pairs per second.

The beacon antenna has an omnidirectional radiation characteristic modified by a rotating parasitic reflecting element. This produces a rotating cardioid pattern which sinusoidally modulates the beacon transmitter pulse pair output with respect to any one reception position. The frequency of this modulation is 15 Hz. The positive going crossover point of this modulation occurs when received from a position due south of the beacon. At this time, a north reference burst is radiated by the beacon transmitter. The relative phase difference between this reference group and the 15-Hz sinusoidal modulation waveform is translated by the airborne receiver circuits into terms of bearing information for display by an instrument in the aircraft.

To increase the accuracy of the bearing information, the RF pulse output from the beacon antenna is also modulated at a frequency of 135 Hz by the use of nine additional parasitic reflectors. The reflectors introduce a superimposed 135-Hz sine wave component on the 15-Hz cardioid pattern. Corresponding auxiliary reference bursts are provided in the transmitter output. They are phased so that the positive going crossover point of the 135-Hz modulation will coincide with the 135-Hz reference burst, with respect to a reception position due south of the beacon. The 135-Hz reference bursts and complete cycles of 135-Hz modulation repeat at angular intervals of 40°, with respect to the rotary 15-Hz cardioid pattern. This improves the accuracy of the obtained bearing.

For purposes of beacon identification, the random squitter pulses are periodically replaced at 740 μ sec intervals by pulse pairs spaced 100 μ sec apart. These evenly spaced groups form a 1,350-Hz tone which is phase locked to the auxiliary bursts and keyed with the beacon identification signal in Morse code.

Radio Test Set AN/ARM-22

Radio Test Set AN/ARM-22 provides range and bearing signals, identical to those of the surface beacon except for tone coding, for testing of airborne TACAN equipment. The test set consists of the following four major units:

1. Range and Azimuth Simulator SM-142/ARM-22.
2. Pulse Generator SG-317/ARM-22.
3. Signal Generator SG-318/ARM-22.
4. Power Supply PP-2110/ARM-22.

A functional block diagram of the test set is shown in figure 5-4.

The power supply provides regulated voltages for the range and azimuth simulator and the pulse generator. The signal generator contains its own power supply circuitry.

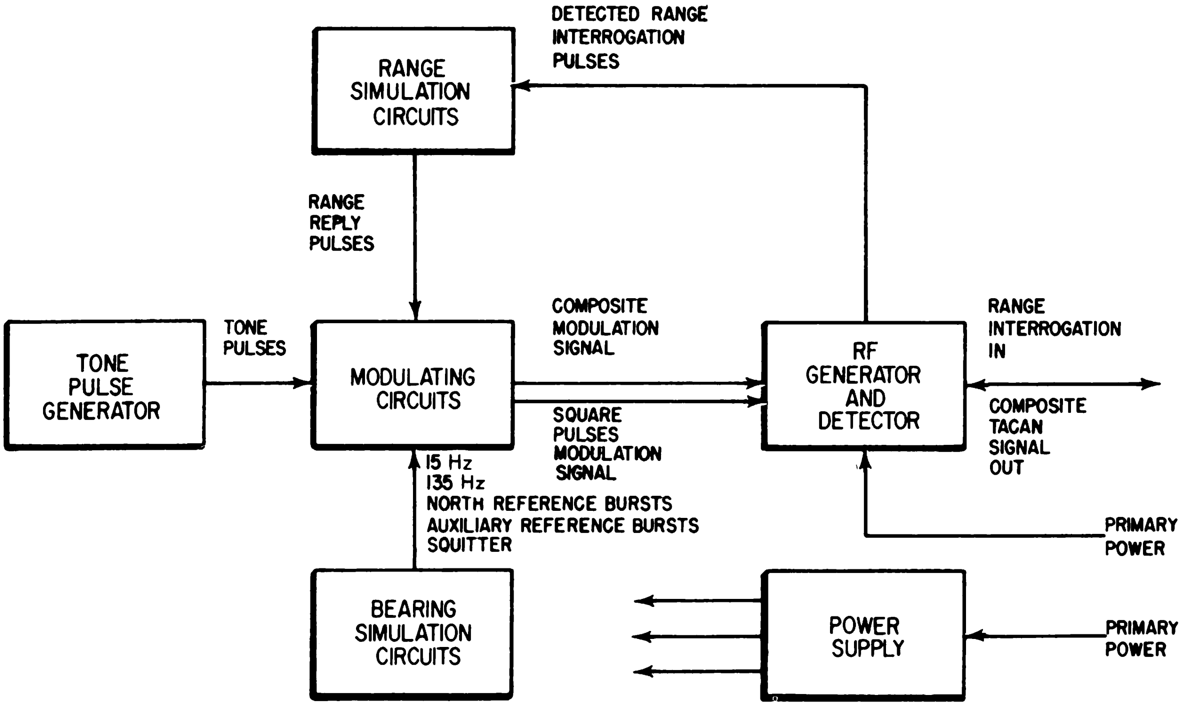
RANGE SIMULATION CIRCUITS
DETECTED RANGE INTERROGATION PULSES
RANGE REPLY PULSES
TONE PULSE GENERATOR
TONE PULSES
MODULATING CIRCUITS
COMPOSITE MODULATION SIGNAL
SQUARE PULSES MODULATION SIGNAL
RF GENERATOR AND DETECTOR
RANGE INTERROGATION IN
COMPOSITE TACAN SIGNAL OUT
15 Hz
135 Hz
NORTH REFERENCE BURSTS
AUXILIARY REFERENCE BURSTS
SQUITTER
PRIMARY POWER
BEARING SIMULATION CIRCUITS
POWER SUPPLY
PRIMARY POWER

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Figure 5-4.—AN/ARM-22 functional block diagram.

The range and azimuth simulator simulates range and bearing information and uncoded tone pulses for the identity tone signal. Bearing information consists of a north reference trigger, auxiliary reference triggers, and 15-Hz and 135-Hz variable phase sine waves. Range information consists of suitably delayed range reply triggers.

The range, bearing, and tone information developed in the range and azimuth simulator is supplied to the pulse generator. The pulse generator circuits develop the correct spacing between pulses of groups, code and shape the output pulses, generate squitter signals, and modulate the pulse output at 15 and 135 Hz. Controls are provided so that range and bearing signals may be made available individually, or combined with squitter signals. The output of the pulse generator, which consists of signals selected by the operator, is then applied to the signal generator. The pulse generator circuits also supply square pulses to the signal generator. These square pulses are synchronized with the shaped video pulses. The square pulse train is identical to the shaped pulse train but is not sine wave modulated. These pulses key the RF generating stages in the signal generator prior to modulation by the pulses.

The signal generator generates crystal controlled RF signals for each of the 126 channels. Channels 1 through 63 operate in a frequency range from 962 through 1,024 MHz; channels 64 through 126 operate in a frequency range from 1,151 through 1,213 MHz. The desired composite video signals from the pulse generator are applied to the signal generator where they are used to modulate RF signals. The signals may be amplitude controlled and applied to the airborne receiver-transmitter under test. When the function selector switch is placed in the PULSE OUT position, the signal generator output is in the form of pulse modulated RF power, thus simulating the beacon output in space. A CWRF output signal is obtained when the function selector switch is placed in the CW OUT position.

POWER SUPPLY.—The power supply unit, shown in block diagram form in figure 5-5, furnishes regulated d-c voltages at + 250v, + 150v, and -120v, and an unregulated d-c voltage at + 28v to the range and azimuth unit and the pulse generator.

Primary a-c power is supplied through jack J1. With the a-c power switch S1 in the OFF position, power is supplied to the stan-by heaters in the three units. When S1 is energized, the heaters are cut off and power is applied to blower

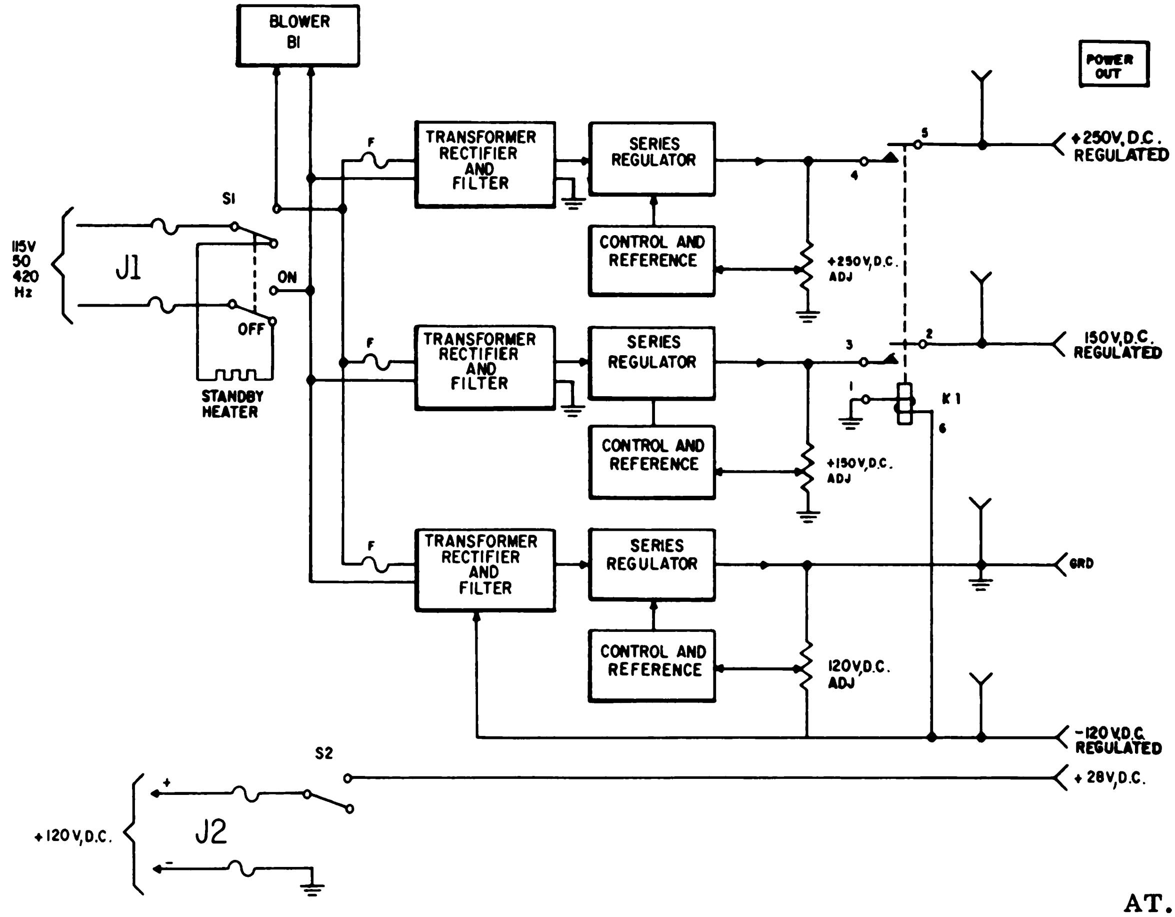

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Figure 5-5.—Power supply, block diagram.

B1 and to three separate power supplies. Each power supply employes standard rectifier and filter circuits and a series regulated output circuit, which is controlled by a gas filled reference tube and a control tube.

Relay K1 protects circuits in the range-azimuth and pulse generator units by preventing application of plate voltages until the bias supply is operating. Controls and monitoring jacks on the front panel permit adjustment of each of the regulated voltages.

Primary d-c power at 28v is supplied through jack J2 and controlled by switch S2.

All power outputs are available at the power output jacks. Each input power line and power supply is separately fused by front panel fuses.

RANGE AND AZIMUTH UNIT.—The range and azimuth unit (fig. 5-6 and fig. 5-7) provides appropriately delayed range reply trigger pulses, north and auxiliary reference burst triggers, simulated bearing signals, 1,350-Hz tone triggers, and a 4,046-Hz test signal.

Range interrogation pulse pairs from the radio set under test are decoded in the signal generator and fed to the simulated range reply circuits. The range decoder circuit decodes range interrogation pulse pairs into a single pulse delayed about 11μsec. Each of these pulses is used by the pulse train generator circuit to produce a pulse train 3,000 sec long, with individual pulses spaced at 222.2-μsec intervals corresponding to 18-mile separation between pulses. A five-position switch selects the mode of operation of the range reply circuits by selecting the proper range selector circuit.

The variable range rate circuit utilizes a motor driven potentiometer to produce a range sweep at a predetermined rate. Each range

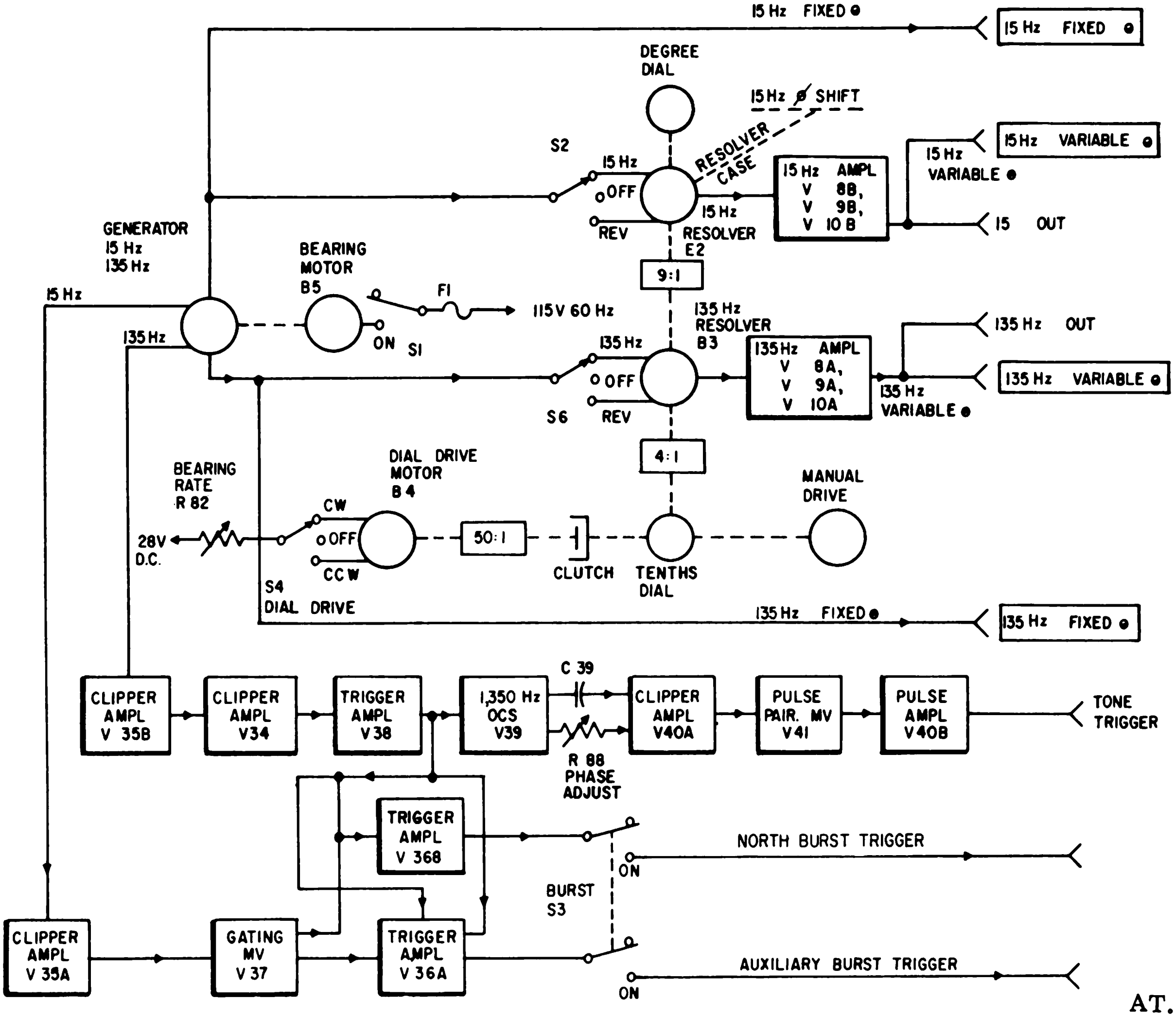

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Figure 5-6.—Range and azimuth unit, bearing and tone circuits, block diagram.

sweep covers fixed limits, according to the setting of the switch. In the variable position of the range switch, a manually operated potentiometer permits continuous variation of range simulating signals from 0 to 195 miles. In the fixed position of the range switch, fixed range steps are available, from 0 to 198 miles, in 18-mile increments.

Each range selector position selects a positive bias, which is fed to the bootstrap delay circuit. In the bootstrap delay circuit, this bias and a pulse from the pulse train generator produce a delayed signal which operates a range gating circuit. In the fixed position of the range switch, the range gate produces a fixed delay gate which opens the coincidence gate to permit the passage of the appropriate pulse from the pulse train. The variable delay range pulses from the range gate, or the fixed delay range pulses from the coincidence circuit, are fed to the efficiency circuit, which divides the pulse count so that only the indicated percentage of appropriately delayed reply pulses is fed to the output circuit. The output circuit converts each range reply pulse to a pulse trigger fed to the pulse generator unit.

A 15-Hz and 135-Hz generator provides the basic signals used by the unit for producing simulated bearing signals. The separate synchronous 15-Hz and 135-Hz sine waves from the generator are fed, respectively, to north reference burst and auxiliary reference burst circuits. The north burst circuit produces a pulse which serves as the north burst trigger. The auxiliary burst circuit produces eight equally spaced pulses between each pair of north burst trigger pulses.

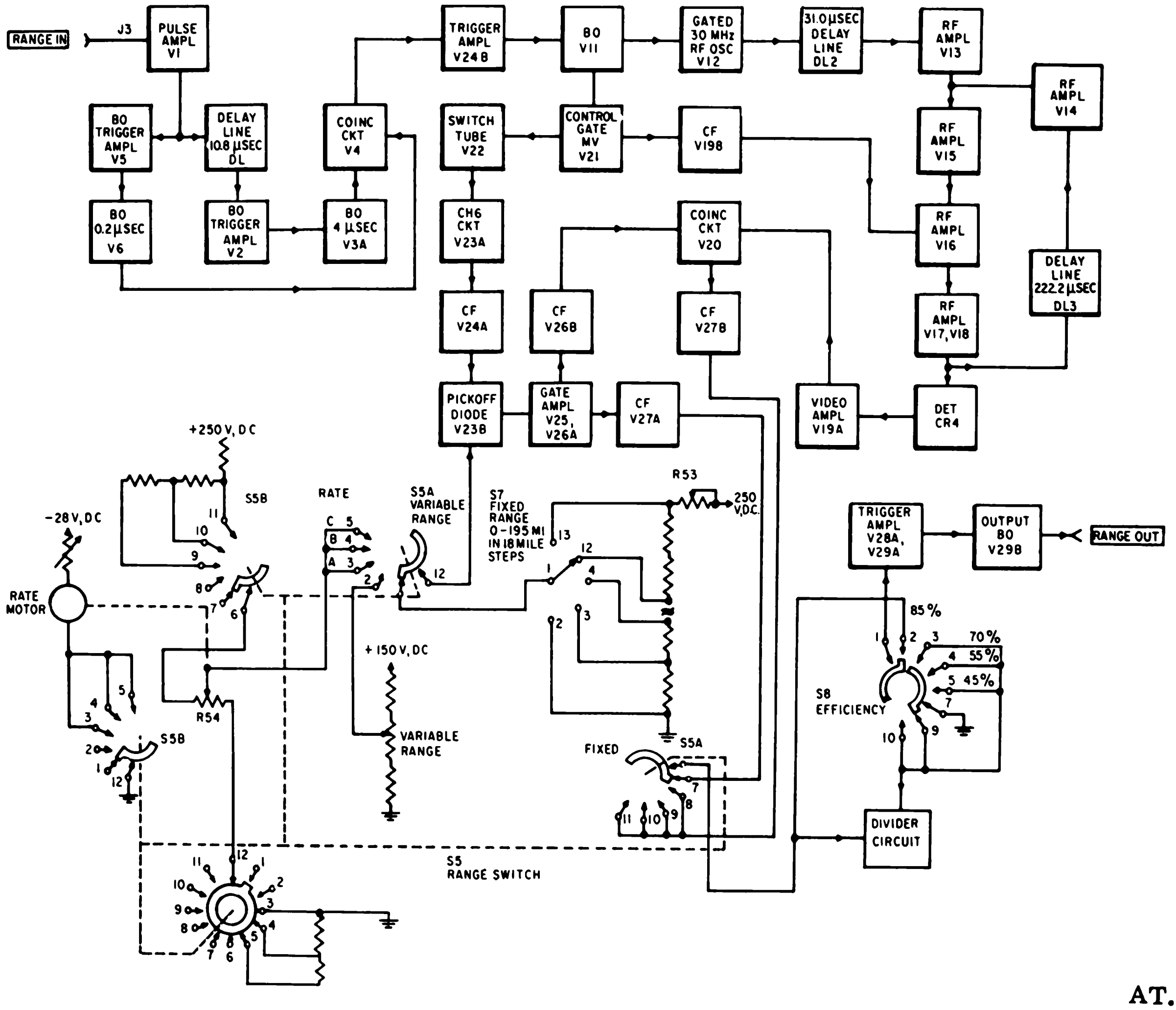

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Figure 5-7.—Range and azimuth unit, range circuits, block diagram.

Separate 15-Hz and 135-Hz sine waves from the generator are fed to phase shift resolvers. These resolvers shift the phase of the 15-Hz and 135-Hz sine waves, with respect to the north and auxiliary triggers, to simulate bearing information.

A 4,046-Hz oscillator in the range and azimuth unit provides a 4,046-Hz signal for testing range circuits in the airborne receiver-transmitter.

A tone pulse circuit produces 1,350-Hz tone trigger pulse groups.

PULSE GENERATOR UNIT.—The pulse generator unit utilizes the tone, range, and bearing signals from the range and azimuth unit for the following purposes:

1. To produce coded pulse groups.
2. To generate random squitter pulses.
3. To combine all outputs to form a properly sequenced coded pulse train for use by the modulating circuits in the signal generator.

The tone trigger, simulated range trigger, and a squitter signal (generated within the pulse generator unit) are fed to the tone squitter circuits. A switch allows selection of separate signals or of a combined squitter-range signal, and permits the tone-range-squitter circuits to produce a properly sequenced pulse train which is

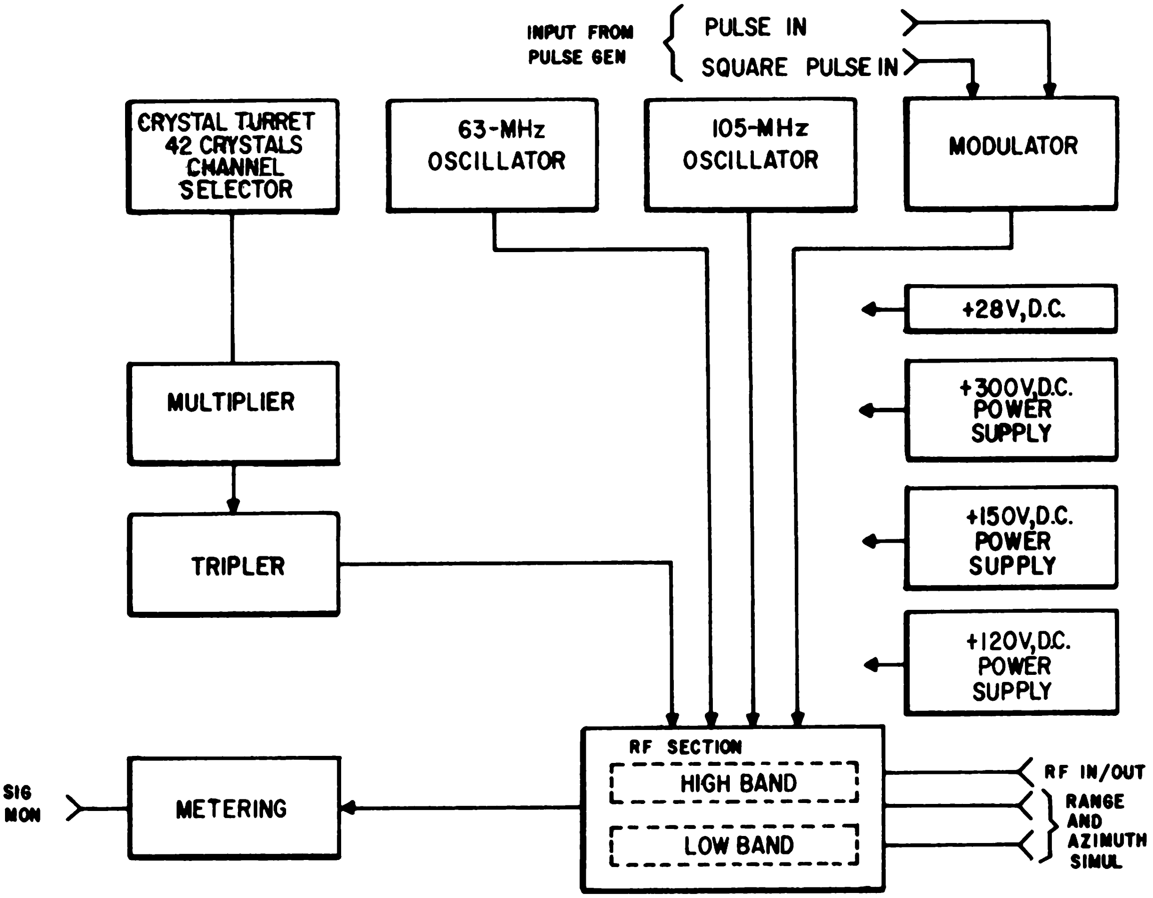

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Figure 5-8.—Signal generator, simplified block diagram.

fed to the burst mixing and gating circuits. The north and auxiliary trigger pulses are fed to separate reference burst circuits.

Each reference burst circuit produces properly spaced pulse groups for each trigger signal. The north reference burst consists of 12 pulses, spaced at 30-μsec intervals, and occuring at a 15-Hz rate. The auxiliary reference burst consists of 6 pulses, spaced at 24-μsec intervals, and occurring at a 135-Hz rate. Since auxiliary bursts are blanked during the occurrence of north bursts, the combined reference burst signals are fed to the burst mixing and gating circuits without interfering with each other. In the mixing and gating circuits, the inputs are combined to form a properly sequenced series of pulses. These sequenced pulses are fed to the pulse coding circuit, where the spacing between pulses of a pair can be varied.

The coded, sequenced pulses are fed to the pulse generator and shaper circuits. In these circuits each pulse is used to produce a pair of 3.5-μsec pulses, spaced 12-μsec apart. All of these pulses are of equal amplitude and are fed to the modulator circuits. The variable phase 15- and 135-Hz sine waves, conveying the bearing information, are fed to the modulator driver circuits and may be used to amplitude modulate the pulse pairs. The output is fed to the signal generator and is also available at a monitor jack for test purposes.

SIGNAL GENERATOR UNIT.—The signal generator unit (fig. 5-8) utilizes the output of the pulse generator to amplitude modulate any one

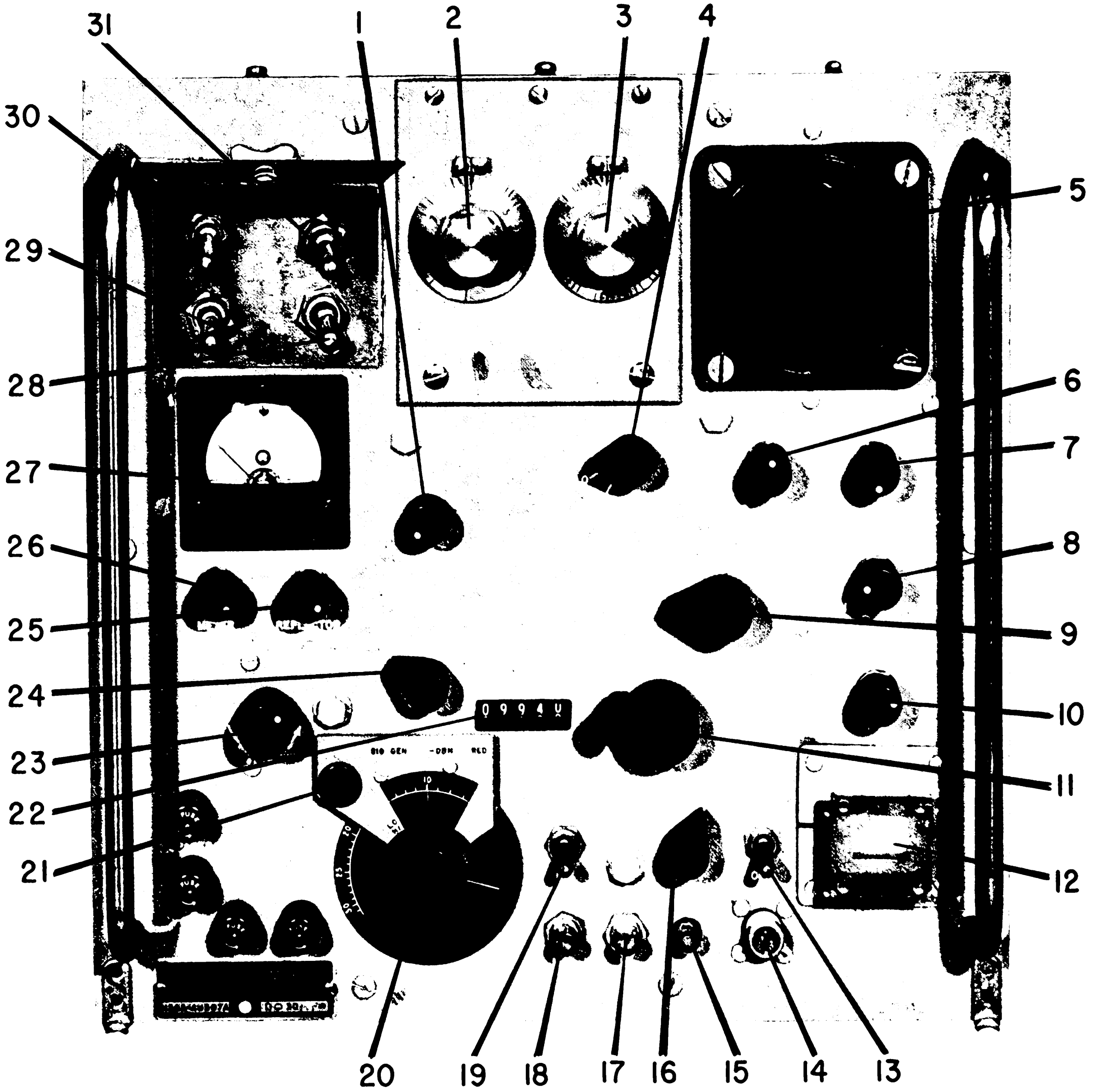

Figure 5-9.—Radar Test Set AN/UPM-32, front panel controls.

Nomenclature for figure 5-9.

1. POWER SET control.
2. PULSE OR GATE WIDTH control.
3. DELAY MULTIPLIER control.
4. DELAY and SWEEP LENGTH switch.
5. Cathode-ray tube.
6. VERT CENTER control.
7. SIGNAL GAIN control.
8. SIGNAL WIDTH control.
9. Function selector switch.
10. SPECTRUM SWEEP FREQUENCY control.
11. Frequency control.
12. RF connection.
13. ON-OFF switch.
14. 115 VAC connector.
15. SIGNAL connector.
16. SIGNAL switch.
17. TRIGGER IN connector.
18. EXT MOD connector.
19. TRIGGER switch.
20. DBM control.
21. Indicator light.
22. FREQUENCY counter.
23. OSC FREQUENCY control.
24. ATTENTUATION switch.
25. REFLECTOR control.
26. METER BALANCE control.
27. Power meter.
28. ASTIG control.
29. MODE GAIN control.
30. FOCUS control.
31. INTENSITY control.

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of 126 output frequencies. This action produces an output signal which consists of RF pulses containing the range, tone, squitter, and reference bursts, all of which are amplitude modulated by the simulated bearing signals at 15 Hz and 135 Hz.

Any one of 42 separate crystals selected by the channel selector controls a primary crystal oscillator. The signal from the primary crystal oscillator, after being multiplied and properly combined with the output of a crystal controlled 105-MHz or 63-MHz oscillator, provides the 126 radiofrequencies. The unit may also be used at these frequencies as a CW generator.

The composite modulating signals from the pulse generator unit enter the modulator drive circuits. After amplification, they are used to modulate various RF stages when the unit is switched to the pulse operation position. The RF signal from the output cavity is fed through a variable attenuator to an RF filter assembly. Then, via a piston attenuator, the RF signal is fed to the receiver-transmitter under test. When the receiver-transmitter under test transmits range interrogation pulses, the coupling circuit directs them to a detector which detects the interrogation pulse pairs and feeds them to the range and azimuth simulator.

The signal generator also contains circuits for measuring the transmitter output power of the receiver-transmitter under test, calibrating the level of the pulsed or CW RF output, and monitoring the various signals.

RADAR TEST SET AN/UPM-32

Radar Test Set AN/UPM-32 is a portable test set designed primarily for use with radar sets operating in the frequency range of 8,500 to 10,500 MHz. It combines in one test set all the functions of a power meter, a frequency meter, a spectrum analyzer, a signal generator, and a general purpose synchroscope. Figure 5-9 illustrates the AN/UPM-32, indicating all of its front panel controls.

PURPOSE

The general applications of the test set are as follows:

1. Measurement of power, frequency spectrum, and frequency pulling of conventional and multipulsed radar transmitters.
2. Measurement of sensitivity and bandwidth of a radar receiver.
3. Measurement of the frequency and spectrum of a radar receiver local oscillator.
4. Adjustment of a radar receiver local oscillator.
5. Measurement of TR recovery time.
6. Observation of video signals.
7. Furnishing pulsed, FM, or CW microwave signals.

From the preceding list of applications, it should be obvious that the AN/UPM-32 is a very versatile test set.

OPERATING PROCEDURES

Through the use of the master function selector switch (number 9, fig. 5-9), the internal circuits may be switched into the desired operation to perform any of the functions previously mentioned.

Power Meter Operation

When it is desired to use the test set as a power meter, input signals from a radar transmitter pass through a calibrated variable attenuator to a temperature compensated power monitor, illustrated in figure 5-10 in block form. The power monitor is composed of a bridge circuit and a power level indicating meter calibrated in milliwatts and dbm (decibels relative to one milliwatt).

Frequency Meter Operation

When the frequency meter function of the test set is used, an absorption type frequency meter is tuned to resonance. (See fig. 5-10.) The resonant frequency meter cavity causes a reduction of the power level in the microwave section at the frequency to which the cavity is tuned. This reduction of power, at the resonant frequency, appears as a dip on the power monitor meter or on the screen of the synchroscope. The resonant frequency (in megahertz) is indicated directly on a front panel counter (22, fig. 5-9) which is geared mechanically to the tuning mechanism of the cavity.

Spectrum Analyzer Operation

For the spectrum analyzer function, the test set's klystron oscillator is frequency modulated by the sawtooth output of a sweep generator. (See fig. 5-11.)

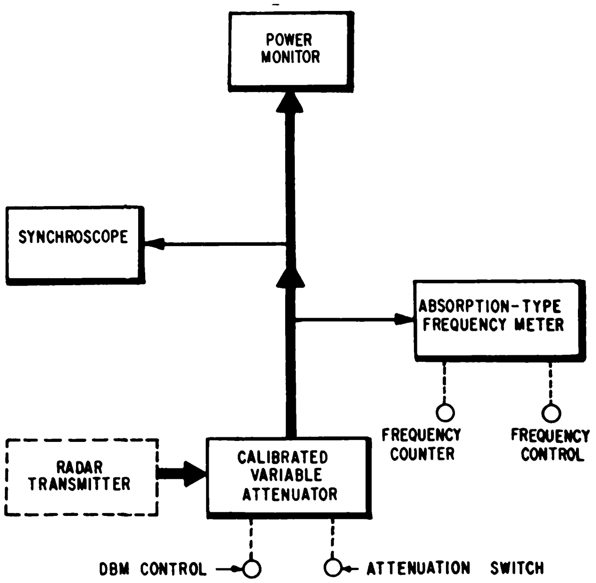
The radar transmitter signal to be observed and the klystron oscillator signal are combined in a mixer to produce heterodyne frequencies which are fed to an IF amplifier. For each radar transmitter pulse, a frequency component of the pulse beats with the klystron oscillator signal to produce a 45-MHz IF signal. For successive radar transmitter pulses, a different frequency component causes the 45-MHz beat frequency to appear because the klystron oscillator is frequency modulated. The detected IF signals are amplified and applied to a cathode-ray tube. Since the horizontal deflection system of the cathode-ray tube is driven by the same sawtooth used for klystron modulation, the CRT pattern is a plot of frequency versus relative power for the input signal.

The test set also includes a gating circuit which permits the observation of the spectrum of any pulse in the output of a multipulsed radar transmitter. For this operation, the radar synchronizer is used to feed a pretrigger to the test set gating circuit to avoid triggering on the wrong RF pulse. This circuit, in turn, generates a pulse which gates the IF amplifier so that any signals applied during the gating period pass through the amplifier. The gating period is long enough to permit only the frequency samples from one radar transmitter pulse to pass through the IF amplifier. The gating pulse may be delayed relative to the pretrigger for the desired pulse selection.

Signal Generator Operation

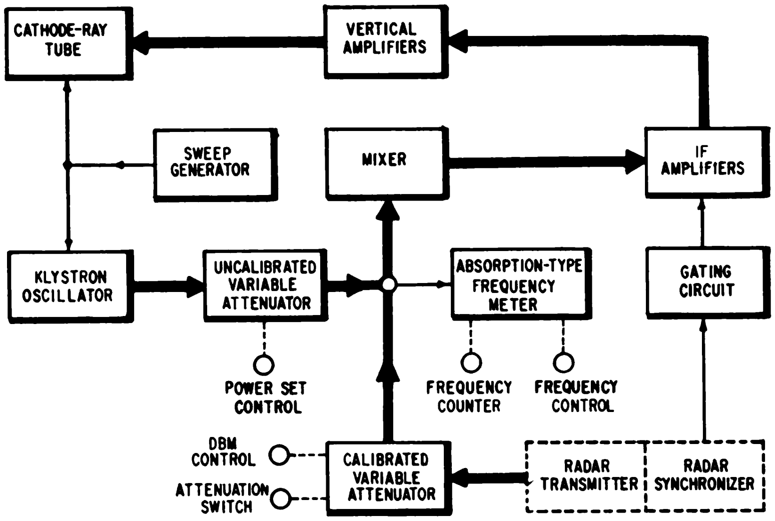
When the test set is used as a signal generator, it supplies FM, pulse modulated, externally modulated, or CW microwave signals. This portion of the AN/UPM-32 is illustrated in block form in figure 5-12.

For the FM and pulse modulated signals, internal circuits provide the modulating waveforms, but a trigger must be provided by an external source. Any desired type of modulation waveform can be applied to the klystron



AT. 403

Figure 5-10.—Power meter and frequency meter operation, simplified block diagram.



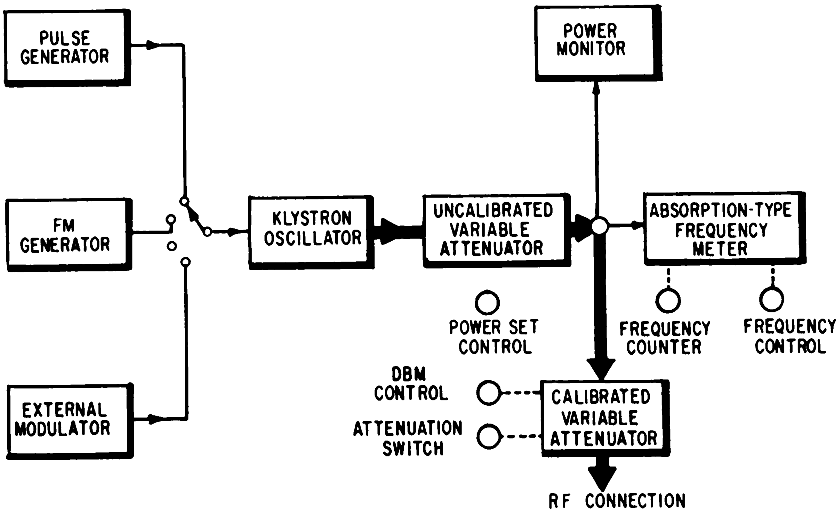
AT.404

Figure 5-11.—Spectrum analyzer operation, simplified block diagram.

oscillator, and the test set will provide correspondingly modulated RF signals. The power level and frequency of all output signals are adjustable to the desired level within the limits of the test set.

Synchroscope Operation

When the test set is operated as a general purpose synchroscope, a video signal is applied to the video amplifiers. The amplified signal is



AT. 405

Figure 5-12.—Signal generator operation, simplified block diagram.

lied to the vertical deflection circuit of the hode-ray tube as illustrated in block form in ure 5-13.

This video signal can be externally applied, it may be an internal signal taken from the xer crystal (detector). The sweep generator, ich drives the horizontal deflection system the cathode-ray tube, must be triggered and chronized with the video signal, either by an ernal trigger source associated with the video nal or by the detected RF pulse from the radar nsmitter.

crowave Assembly

The microwave assembly makes possible the asurement of the power level and frequency input and output signals. The assembly consts basically of a block containing waveguides l attenuating sections. Within the assembly h the klystron signal and RF input signals are xed to obtain a spectrum pattern. Signal flow in the assembly depends upon the setting of the function selector switch to the desired mode of operation.

With the function selector switch on **MIXER** position, energy flow in the assembly is illustrated in figure 5-14. The power set attenuator adjusts the power level of the klystron signal. Because the klystron oscillator is sawtooth modulated by the sweep generator circuits (fig. 5-11), its output frequency varies linearly during the sawtooth excursion. Therefore, if the frequency meter is tuned to a frequency within the range covered by the klystron output, a sharp reduction in power level occurs at this particular frequency. This reduction appears as a dip in the pattern displayed on the CRT indicator. The frequency of the klystron may then be read directly, in megahertz, from the frequency meter Z304.

With the function selector switch in the NORMAL or GATED position, two signals are present in the microwave assembly. (See fig. 5-15.) The

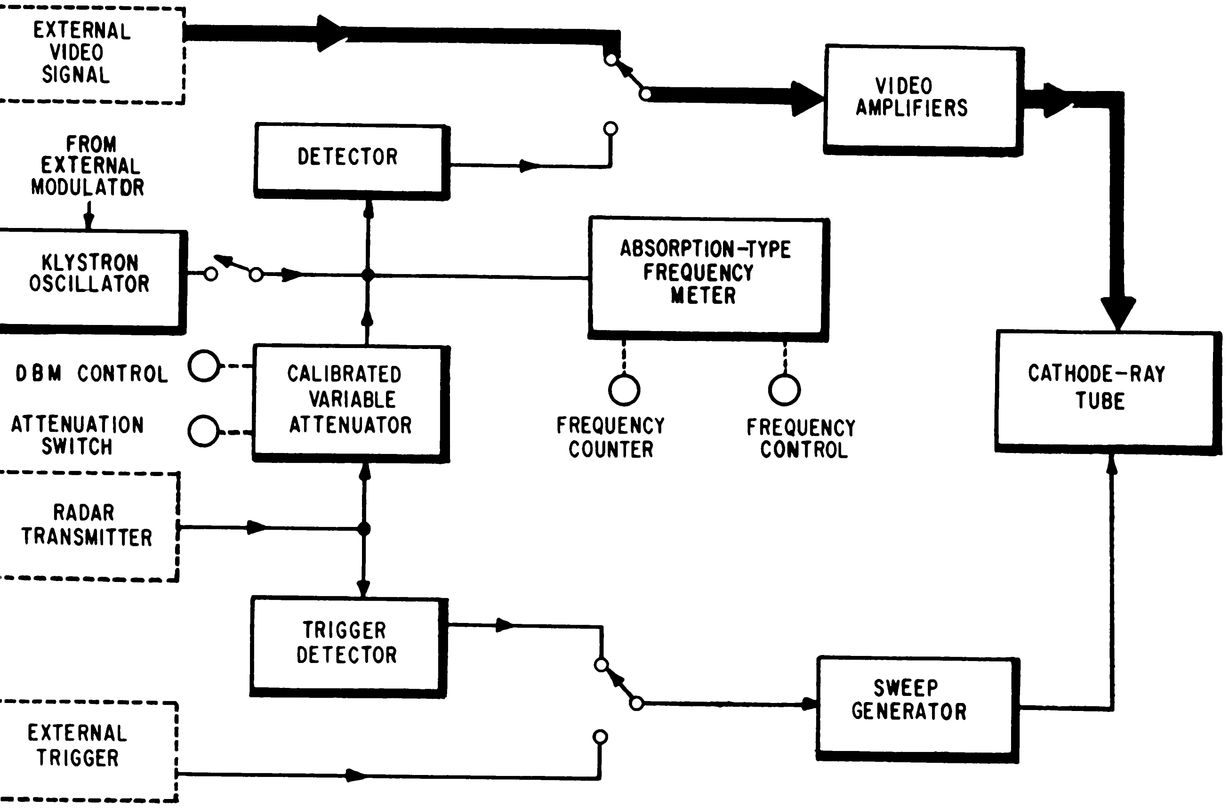
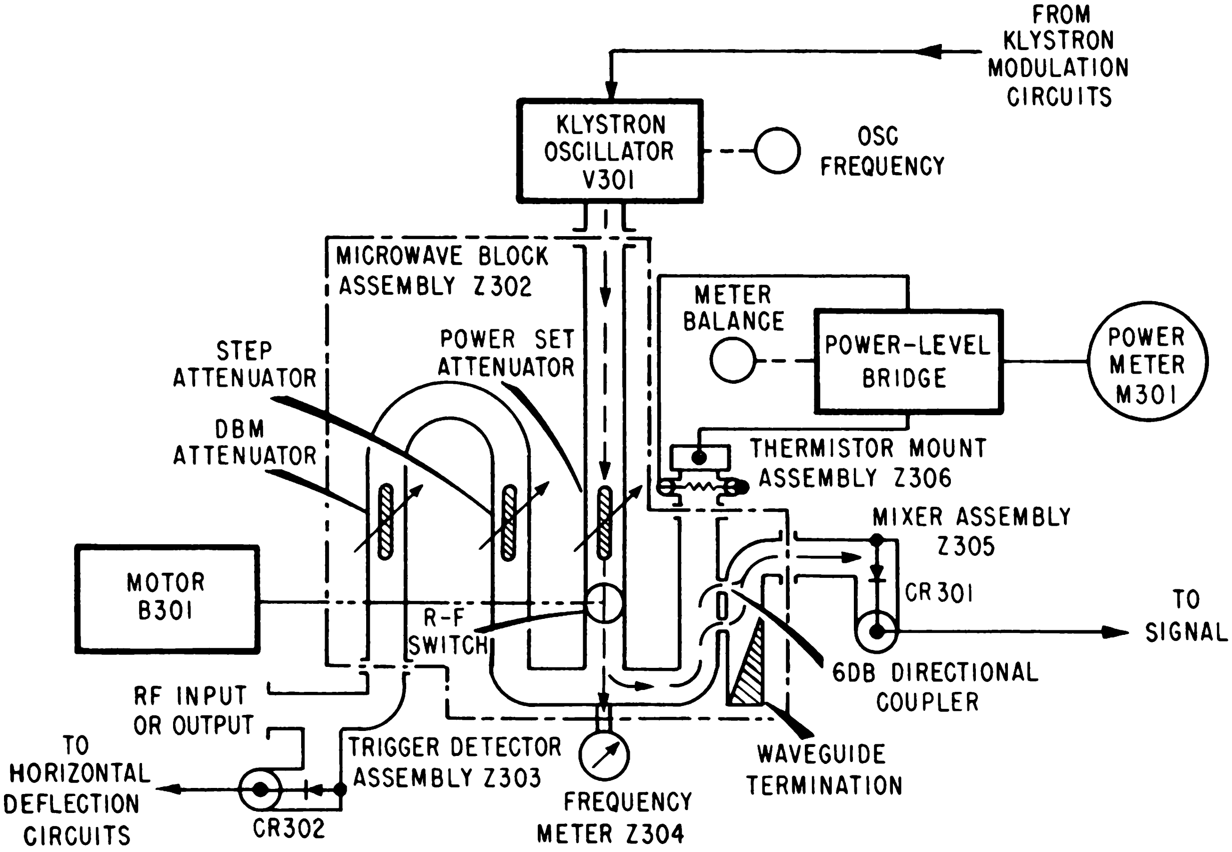


Figure 5-13.—Synchroscope operation, simplified block diagram. AT. 406



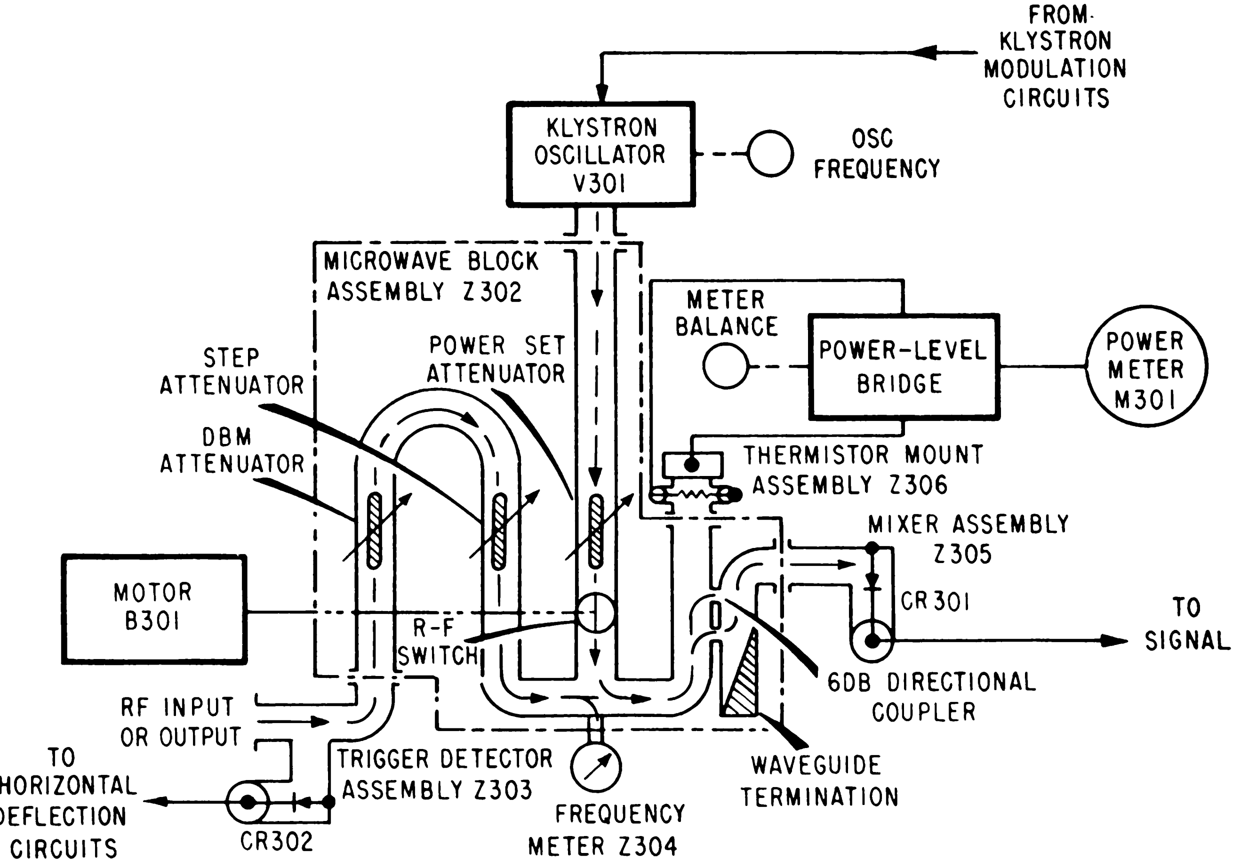
AQ. 320

Figure 5-14.—Energy flow in microwave assembly, function selector switch at MIXER.

klystron signal and the transmitter signal are mixed in the mixer crystal which produces heterodyne frequencies. The 45-MHz component appearing during each radar output pulse passes through a tuned filter network to the IF amplifier stages. Because of the linear sawtooth modulation applied to the klystron, the klystron signal beats with a different frequency component of the radar output during each transmitted pulse interval to produce this 45-MHz beat frequency. Hence, the amplitude of each 45-MHz pulse is a measure of the power contained in the particular magnetron frequency component producing it. The magnetron spectrum is thus produced and appears on the CRT indicator. The technician uses this presentation to observe the ouput waveform of a radar transmitter. The waveform will indicate correct operation, magnetron pulling or pushing, frequency drifting, and other indications of poor transmitter spectrums.

When the function selector switch is placed in the PWR-FREQ METER position, the radar transmitter power is fed through the microwave assembly as shown in figure 5-16. The RF switch is closed; hence there is no power division at the tee junction nor can any klystron power reach the thermistor mount. This permits measurements of the power level of the incoming signal. The step attenuator should be at its minimum (LO) position.

For the PULSE MOD, FREQ MOD, and EXT MOD positions of the function selector switch, signal flow is shown in figure 5-17. The power



AQ. 321

Figure 5-15.—Energy flow in microwave assembly, function selector switch at NORMAL or GATED.

vel of the klystron RF signal is set by the power et attenuator. The frequency of the signal is in-cated by the frequency meter which is used in onjunction with either the power level indicating eter or the synchroscope pattern on the CRT. nce there is an equal division of power in the e junction following the RF switch, the reading the power level bridge meter, as modified by e DBM attenuator dial reading, gives an ac-urate indication of the power level of the test et output signal. The signal reaching the mixer ystal is detected, and the signal, which is the odulation waveform, can be viewed on the CRT setting the signal switch at INT if desired.

rigger Detector Assembly

The trigger detector assembly (Z303, fig. -17) consists of a removable mount attached the rectangular waveguide section at the input of the microwave assembly. The mount contains a crystal rectifier element (CR302) and functions as a fixed tuned detecting section. Isolation from the main waveguide is provided by an iris which attenuates the energy from the main waveguide about 35 db to protect the crystal from burnout.

DBM Attenuator

The DBM attenuator consists of a rectangular glass vane coated with a resistive material. The vane is mounted inside the waveguide parallel to the narrow wall, and its position is continuously adjustable (by the DBM control) from the narrow wall toward the center of the waveguide. The maximum attenuation introduced by the vane (near the center) is approximately 50 db. The calibration of the DBM dial accounts for this attenuation and the known losses in the microwave block.

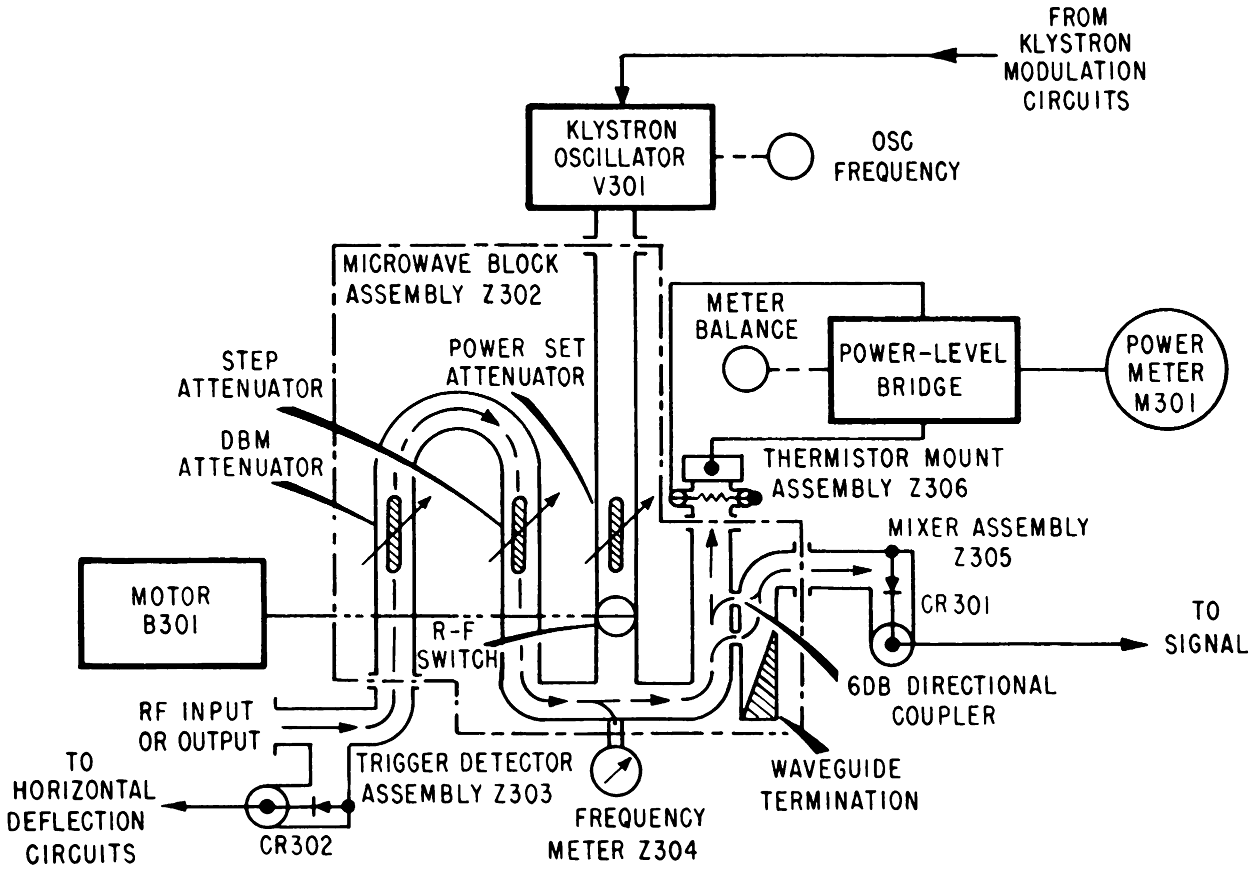


Figure 5-16.—Energy flow in microwave assembly, function selector switch a PWR-FREQ METER.

AQ.322

Step Attenuator

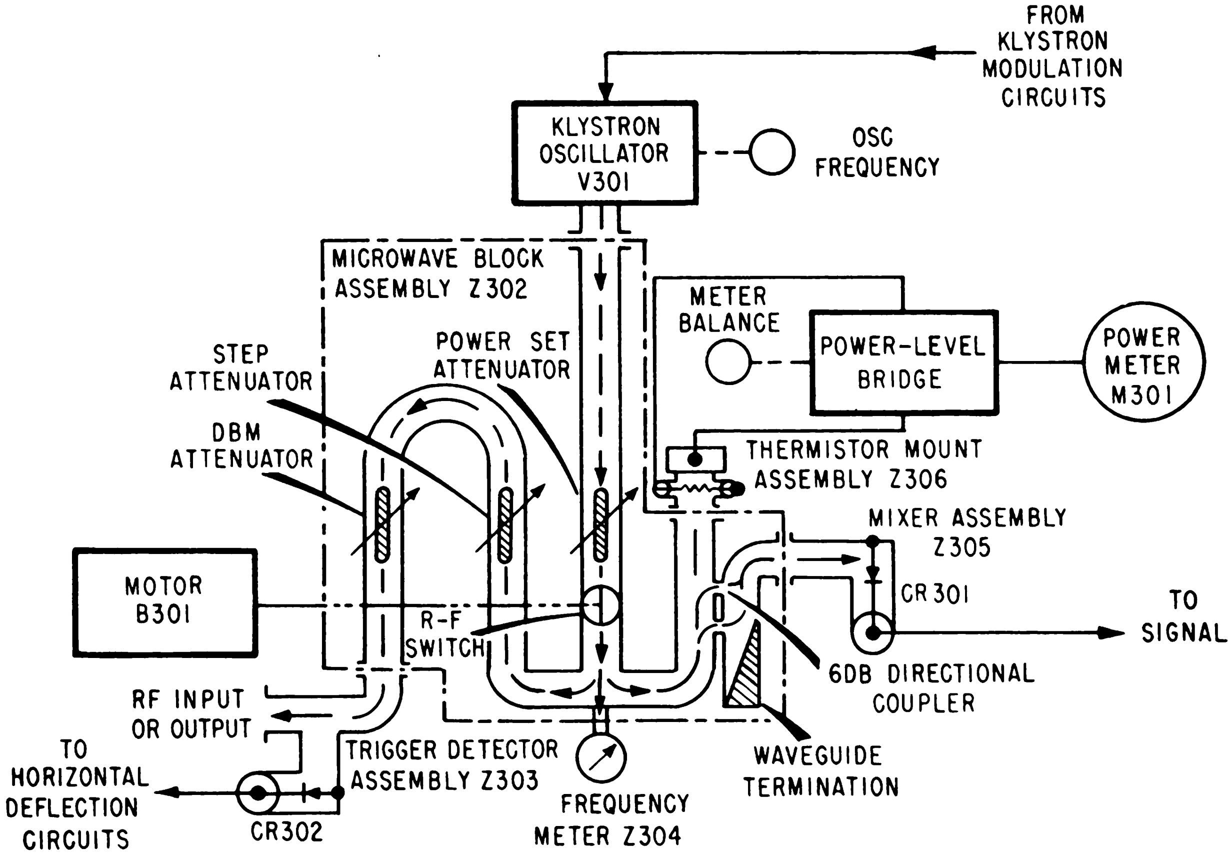
The step attenuator is constructed in the same manner as the DBM attenuator. The step attenuator is controlled by the ATTENUATION switch, which has two settings, HI and LO. In the HI position, the vane is near the waveguide center; in the LO position, it is adjacent to the narrow wall. For the HI position of the switch, the step attenuator introduces about 50 db of attenuation in the waveguide run.

RF Switch

The RF switch consists of a cylindrical element which closes off the waveguide leading to the klystron when the function selector switch is on the PWR-FREQ METER position. The axis of the switching device is paralled to the broad walls of the waveguide. The device has a rectangular hole through it, which lines up with the waveguide for the open position and rotates through a quarter turn to close off the waveguide run to the klystron. A metallic window which projects part way across the guide opening inside the device serves as an impedance matching device for the waveguide tee.

RF Oscillator

The microwave oscillator tube (V301) used in the test set is a reflex klystron which operates on the principle of velocity modulation. The klystron may be tuned either mechanically or electrically. Mechanical tuning is accomplished from the top of the klystron by the OSC FREQUENCY control. Electrical tuning is accomplished by the modulation sawtooth from the modulation sweep generator circuits and by the REFLECTOR control.



AQ. 323

Figure 5-17.—Energy flow in microwave assembly, function selector switch at PULSE MOD, FREQ MOD, or EXT MOD.

NOTE: A detailed discussion on the operation of the reflex klystron is given in Basic Electronics, NavPers 10087-C, Vol. 2.

Power Set Attenuator

The power set attenuator consists of a small rectangular glass vane coated with a resistive material. The adjustment of the vane position within the waveguide is continuous, but the assembly is not calibrated. For the maximum attenuation position near the waveguide center, the attenuator decreases the level of the klystron output signal by 20 to 25 db.

Frequency Meter

The frequency meter (Z304) consists of a circular high-Q cavity with a movable concentric tuning plunger. The frequency meter is fitted into the microwave assembly and coupled to the waveguide by means of a circular iris, and the entire assembly is hermetically sealed. The tuning plunger mechanism is geared to the frequency counter which indicates the resonant frequency of the cavity in megahertz.

Thermistor Mount Assembly

The thermistor mount assembly (Z306) is comprised of a short waveguide section terminated in a housing which contains a thermistor bead. The bead is sensitive to microwave energy, and its resistance changes in proportion to the level of energy in the waveguide. The assembly is mounted to the microwave section and fixed tuned at the factory. A cylindrical subassembly is located on one side of the thermistor mount assembly to hold a disk thermistor. This thermistor has a negative temperature coefficient of resistance. The resistance changes in the disk thermistor compensate the power level bridge circuit for the effects that changes in the ambient temperature produce in the resistance of the thermistor bead.

Mixer Assembly

The mixer assembly (Z305) is similar in construction to the trigger detector assembly (Z303), and it contains the same type crystal cartridge. When the function selector switch is on the MIXER, PWR-FREQ METER, GATE ADJ, PULSE MOD, EXT MOD, or FREQ MOD position, the mixer crystal acts as a simple RF detector. For operation in the NORMAL and GATED positions of the function selector switch, the radar transmitter signal and the klystron signal are both present, and the output of the mixer contains beat frequencies because of the nonlinear detection characteristic of the crystal. The mixer assembly also contains a 3-db isolation pad which is adjusted when installed and must not be disturbed by the field maintenance technician.

TIME-DOMAIN REFLECTOMETRY

Time-domain reflectometry (TDR) is a measurement concept beginning to be widely used in the analysis of wideband systems. The art of determining the characteristics of electrical lines by observation of reflected waveforms is not new. For many years power-transmission engineers have located discontinuities in power-transmission systems by sending out a pulse and monitoring the reflections. Discontinuity is defined as any abnormal resistance or impedance that interferes with normal signal flow.

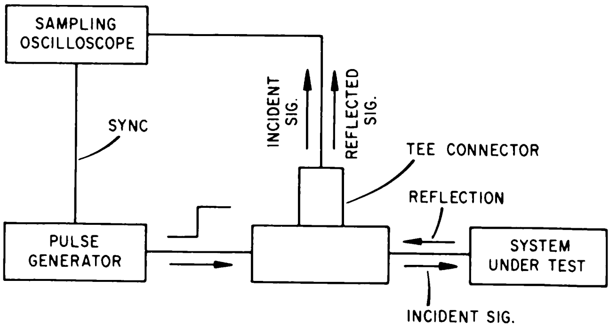
TDR is particularly useful in analyzing transmission systems because the amplitude of the reflected signal corresponds directly to the impedance of the discontinuity, and the distance to the discontinuity can be determined by measuring the time required for the pulse to travel down the line to the reflecting impedance and back to the monitoring oscilloscope.

TDR BASICS

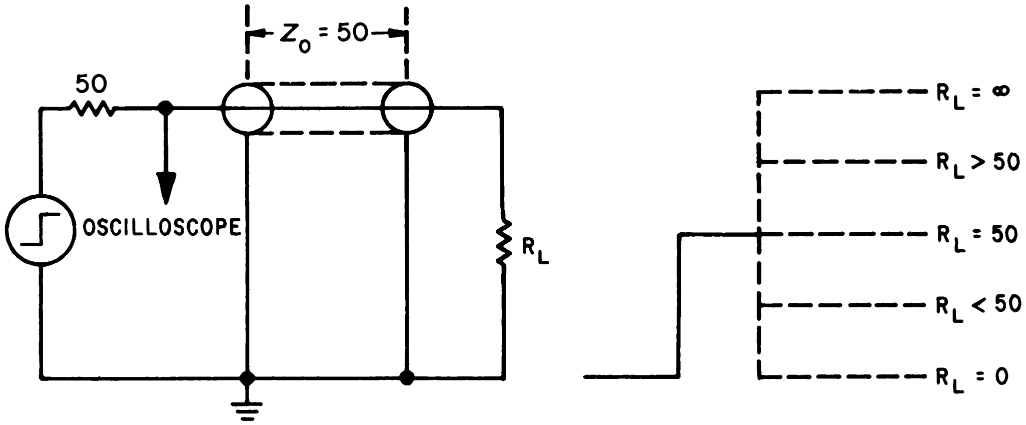
The TDR analysis consists of the insertion of a step or pulse of energy into a system and the subsequent observation, at the point of insertion, of the energy reflected by the system. Several arrangements are possible, but the following procedure is used with the newer, specialized reflectometers. (See fig. 5-18.) A fast (or incident) step is developed in the pulse generator. This step then passes through a TEE connector and is sent into the system under test. The sampling oscilloscope is attached to the TEE connector, and the incident step, along with the reflected waveform, is displayed on the CRT. Analysis of the magnitude, duration, and shape of the reflected waveform will determine the type of impedance variation in the system under test.

Resistive Loads

If a pure resistive load is placed on the output of the reflectometer and a step signal applied, a signal whose amplitude is a function of the resistance (fig. 5-19) is observed on the CRT. If the line is terminated in its characteristic impedance (Z_0) as shown in figure 5-19, there will be no reflected signal and the signal observed on the CRT will remain flat; but if the impedance (R_L) at the termination is greater or less than Z_0, then reflections (standing waves ratio (SWR)) will exist. The amplitude of the reflected signal is proportional to the value of R_L. If R_L is greater than Z_0, the reflected signal will be in phase with the incident signal; and when applied to the CRT, it will add to the incident signal. If R_L is less than Z_0, the reflection will be 180° out of phase with the incident signal; and when applied to the CRT will subtract from the incident signal. The dotted lines in figure 5-19 represent the composite signal (incident plus the reflected) observed on the oscilloscope. The



AT. 407
Figure 5-18.—Typical time domain reflectometer.



AT.408

Figure 5-19.—Step signal-height variations resulting from different resistive loads.

ne from the start of the step to the reflection presents twice the distance to the discontinu- . This is the time it takes the step to travel wn the line to the discontinuity and return.

It is good practice to separate the system der test from the TDR unit's tee connector by least 8 inches of 50-ohm cable. Such a sep- ation moves the reflections away from the ading edge of the step, so that overshoot and nging are not superimposed on the observed gnal.

eactive Loads

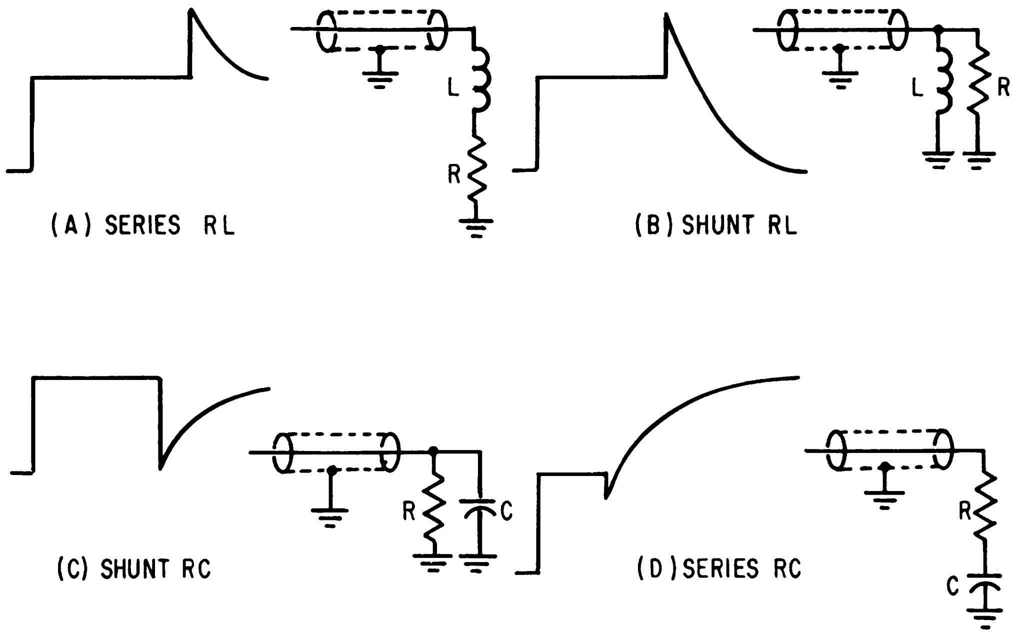
The waveform of reactive loads (fig. 5-20) pends upon the time constant formed by the ad and the 50-ohm source. The series RL net- rk in (A) of figure 5-20 appears as an open e instant the step voltage reaches it because e inductor L offers maximum impedance to e change in current caused by the step volt- e. Therefore, the reflected signal is in phase th the step voltage and is additive. This ex- ains the sharp rise in voltage. However, as on as the inductor saturates, the only opposi- n to current is resistor R; and since L satu- tes at a nonlinear rate, the voltage drops at nonlinear rate from the peak of the spike to e same level as the flat portion of the step ltage. At this time the only load seen by the ne is the 50-ohm resistor which is equal to e characteristic impedance of the line, and the flections cease until the next step appears at e termination and the cycle repeats itself.

The waveshape in figure 5-20 (B) can be understood by remembering that L appears as an open to the fast rising step voltage the instant it is felt at the termination; but as the inductor saturates, it offers less and less opposition to current until it is completely saturated (0 ohm). Since the inductor is parallel to R, the termination is a short and the reflected wave is 180° out of phase with the incident wave. Since L saturates at a nonlinear rate, the voltage declines at a nonlinear rate. A similar analysis can be made of the transmission lines with the RC terminations shown in (C) and (D) of figure 5-20.

The analysis just made of the different types of discontinuities explains the usefulness of TDR. Not only can a discontinuity be determined, but through proper analysis you can determine whether it is resistive, inductive, or capacitive, and whether it is in series or parallel with the load.

TDR IN PRACTICE

TDR discontinuities are clearly separated in time on the CRT; it is easy to see the mismatch caused by a connector even if a bad discontinuity is present elsewhere in the system. By using the aforementioned analysis, it is possible to establish which connector is troublesome and in what way. Once it is determined that a discontinuity appears in a waveform, it is simple to locate it in the system. A timesaving way of doing this is to calibrate the system so that 1 centimeter on



AT. 409

Figure 5-20.—TDR reactive load characteristics (time constant = 1).

the horizontal axis is the equivalent of a certain number of feet for the transmission system under test. The limiting factor is the system rise time, and any closely spaced discontinuities will appear as a single discontinuity.

The finite rise time also limits the size of the distinguishable reactive impedance response. For example, a small shunt capacity in a 50-ohm system will cause the waveform to depart from the ideal response (fig. 5-21).

The maximum observable line length is a function of the repetition rate chosen. This rate determines the duration of the pulse after its rise. For example, a 200-kHz repetition rate permits the use of TDR devices with up to 1,000 feet of air dielectric cable or 670 feet of polyethylene dielectric coaxial cable. The speed at which a wave travels through a transmission system is determined by the system's velocity constant; thus a wave travels faster through air than through polyethylene. This explains the difference in maximum lengths of coaxial cable that can be checked using a particular repetition rate on the TDR—the longer the cable, the lower must be the repetition rate.

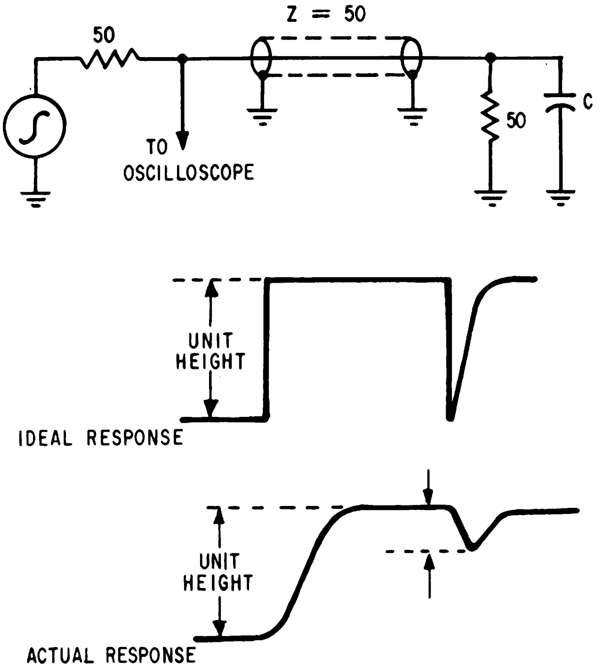
RANGE AND RESOLUTION

Assuming that the total impedance (Z_0) equals 50-ohms, a resistance between 0.025 ohm and 100 K ohms may be measured. Because the height of the reflection is directly proportional to the resistance encountered, the resistance may be determined by the use of a precalculated transparent overlay.

One common use of TDR is in analyzing a coaxial cable. The amount of impedance variation that can be detected in a long section of cable is a function of the flatness of the top of the incident step. If this step is flat within ± one-half percent, impedance variation of one-half ohm along the cable can be detected, corresponding to a one percent check on cable impedance. Thus, irregularities in cable makeup resulting from variations in the braiding process or tightness of the insulating jacket show up clearly.

TDR TECHNIQUES

For applications where the output of a test system is of interest, a dual-channel sampling oscilloscope can be used in a TDR configuration

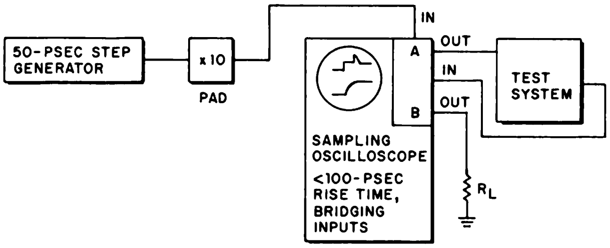


AT. 410

Figure 5-21.—Small shunt capacity in system degrades ideal response.

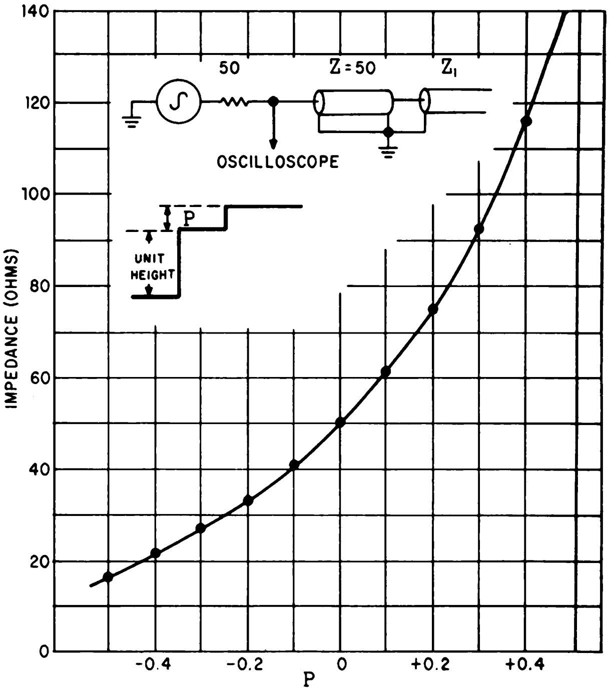
to display both the input and transmission characteristics of the system (fig. 5-22).

The step generator is connected to the sampled channel and an accurate 50-ohm termination is connected to the output for the initial calibration. This termination can be a one percent film type load resistor with short lead lengths. Prior to removal of the 50-ohm termination and connection of the test system, the vertical gain of the oscilloscope is adjusted to give a 10-centimeter step.



AT. 411

Figure 5-22.—Dual-channel oscilloscope analysis of reflection and transmission characteristics.



AT. 412

Figure 5-23.—Curve for the conversion of normalized reflected pulse height into system impedance.

The magnitude and location of reflections can be viewed more closely by selection of an appropriate time scale and vertical magnification. Calibration of the horizontal reflection allows rapid physical location of points of interest. Calibration of the vertical axis in terms of the reflection coefficient (the change in amplitude of the flat portion of the incident waveform caused by the reflected signal; for example, p of figure 5-23) allows direct interpretation of cable impedance at the discontinuity.

With the sampling oscilloscope calibrated, cable impedance can be determined from the height of the reflected step. The graph shown in figure 5-23 may be used to translate step heights into impedance.

ANALYZING TERMINATIONS

Departure from 50 ohms in a termination or cable connector can cause large reflections in a pulse system or a large voltage standing wave ratio (VSWR) in a system that carries primarily sinusoidal signals. Because of human errors in the assembly process, even the best connectors unfortunately cause reflections or a varying VSWR. Expensive connectors, therefore, do not insure freedom from unwanted reflections, but TDR helps locate unacceptable connectors by rapidly showing where the mismatches are, how bad they are, if they are resistive, capacitive, or inductive, and whether series or shunt. Figure 5-24 shows a step being propagated from a section of RG9A/U into a load. The connector on the load and the cable are the General Radio Type 874. Four different cases are shown with varying loads, thus illustrating how the connection and the load can be analyzed by use of the TDR. With different connectors and loads, the small mismatches (discontinuities) take on different impedance characteristics and the reflected signals change. This change is also reflected in the wave shape viewed on the oscilloscope. A comparison between these signals and those of a normal system can be made by using an overlay showing the pattern of a normal system.

Cable Impedance

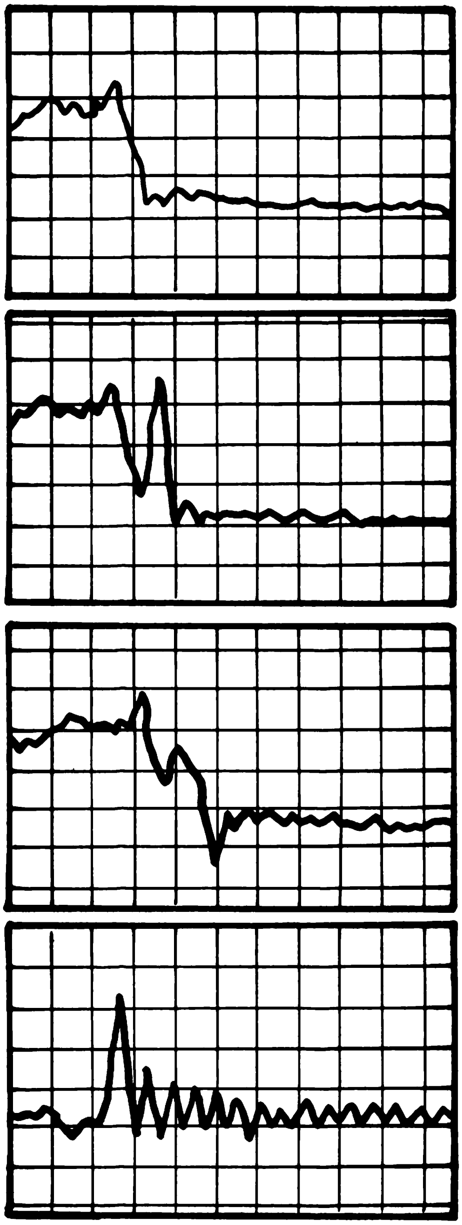
The most convenient method of reflectometer use in making precise measurements of cable impedance is to connect a section of air dielectric line with precisely determined impedance between the test cable and the TDR unit. The step height through the air dielectric line section sets the 50-ohm level. Variations from this level in the test cable are noted, and the impedance of the cable is calculated (fig. 5-25). In this test, the impedance level of the test line is

$$Z_0 = 50 \frac{1 + p}{1 - p}$$

where p is the reflection coefficient of the reflected mismatch. The change in amplitude shows p to be + 0.03, so

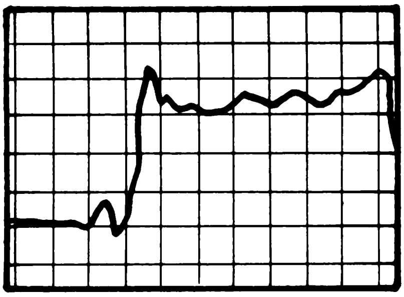
$$Z_0 = 50 \frac{1.03}{0.97} = 53 \text{ ohms}$$

The impedance of a long section of coaxial cable would be exactly Z_0 if there were no line losses. However, most cables have a small series loss and a negligible shunt loss. This series resistance adds to Z_0, causing the impedance level, as observed at one end of a cable, to increase as longer sections of cable are added.



AT. 413

Figure 5-24.—Waveforms resulting from the use of different loads. Horizontal scale 0.4 μsec/cm; vertical scale 0.5 percent/cm.

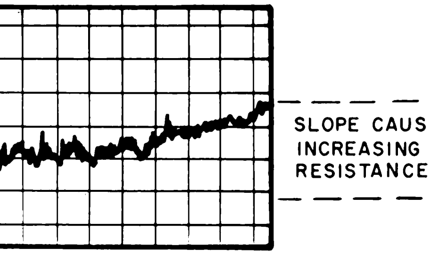


AT. 414
5-25.—Oscillograph of step from air dielectric line into test cable.

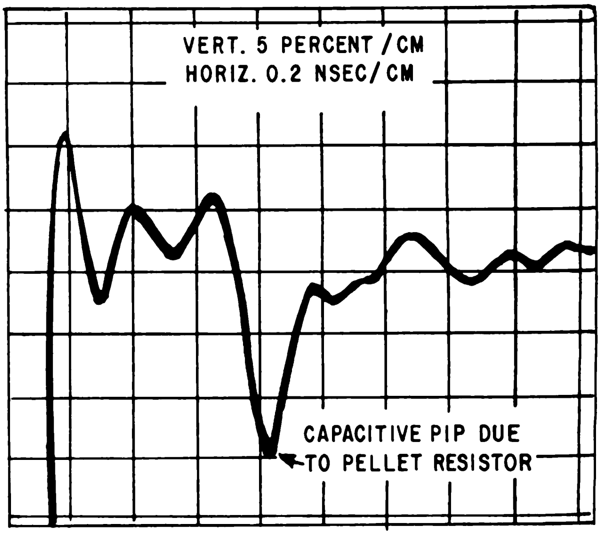
ɔpe on the step height that results from
reasing impedance is evident in figure

ɜr applications in which the TDR method
ysis can be used effectively are the com-
characteristic analysis and antenna anal-
ne components can be placed in an appro-
ig and the TDR method used to determine
hunt capacity and series inductance (fig.

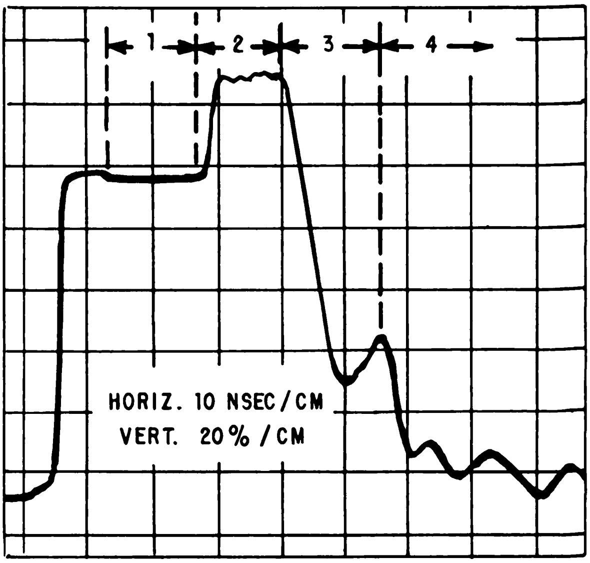
ɛstigation of antennas will reveal that the
ttern is not simple, but instead presents
lex reactive profile (fig. 5-28). Once the
profile for a particular antenna is deter-
any improper construction details can be
d and the proper corrective action as-
ed.



AT. 415
5-26.—Trace of cable shows construction
ılarities and increasing series resist-



AT. 416
Figure 5-27.—Resistor checked for shunt capacity with special jig.



AT. 417
1. 50-ohm feedline. 3. Short at end of antenna.
2. 75-ohm antenna. 4. Rereflections.
Figure 5-28.—Scope trace of antenna reactive profile.

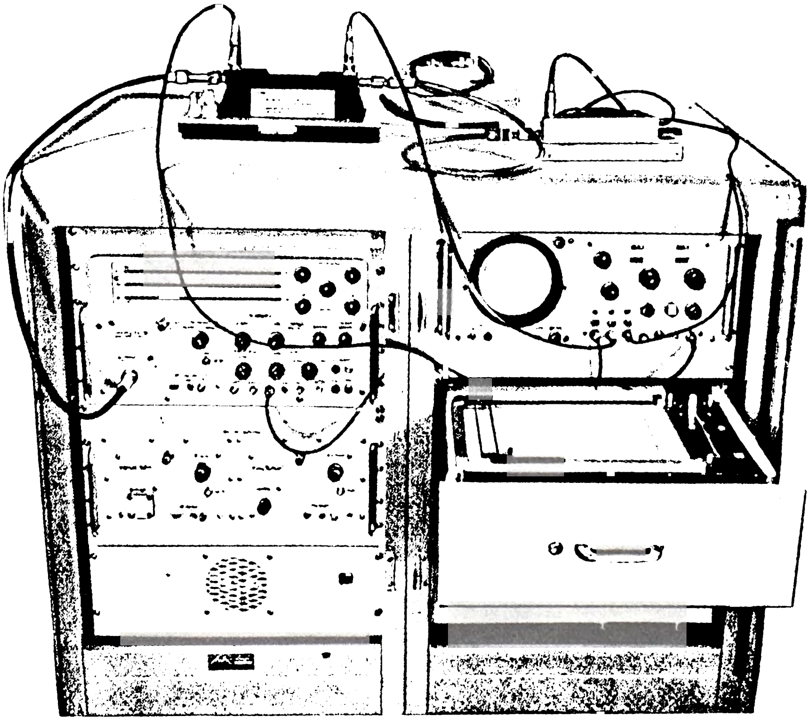
FREQUENCY-DOMAIN REFLECTOMETRY

Frequency-domain reflectometry (FDR) is a fast, simple, and reliable technique developed to locate defects in microwave cables and waveguide systems connecting receivers, transmitters, and antennas. Although the name sounds complicated, the technique is easy to use and permits direct readout of cable distance (in feet) to the impedance discontinuity (fault). (See fig. 5-29.) This system has developed an impressive record of reliability, greatly reduced service time, and improved service standards. Because the new system checks cables at their actual operating frequencies, discontinuities outside those frequencies will not affect the test. When measurements indicate a fault, its location (in terms of distance in feet from the point of test) can be precisely determined. Repairs, therefore, can be made quickly and efficiently.

FDR VERSUS TDR

Until now, cables have been tested primarily by means of time-domain reflectometry, a system which has several severe limitations. For example, TDR makes measurements covering a spectrum determined by its pulse characteristics and therefore identifies all discontinuities or parameter changes including those outside the operating frequency range which do not affect system operation. With FDR, however, the analysis is made at the actual operating frequency band of the microwave system, thereby assuring proper system performance at the operating frequencies.

While FDR works in waveguide and band-limited systems including transmission networks that contain filters, TDR cannot work in such systems because it requires a transmission line that passes the whole spectrum from the fundamental



AT. 418

Figure 5-29.—FDR cable testing system.

quency (2 MHz to 5 MHz) to the highest har-
ic (15 GHz). Waveguides which act as high-
s filters cannot transmit TDR pulses. Simi-
y, TDR cannot see through low-pass or
dpass filters because these eliminate the low-
quency harmonics.

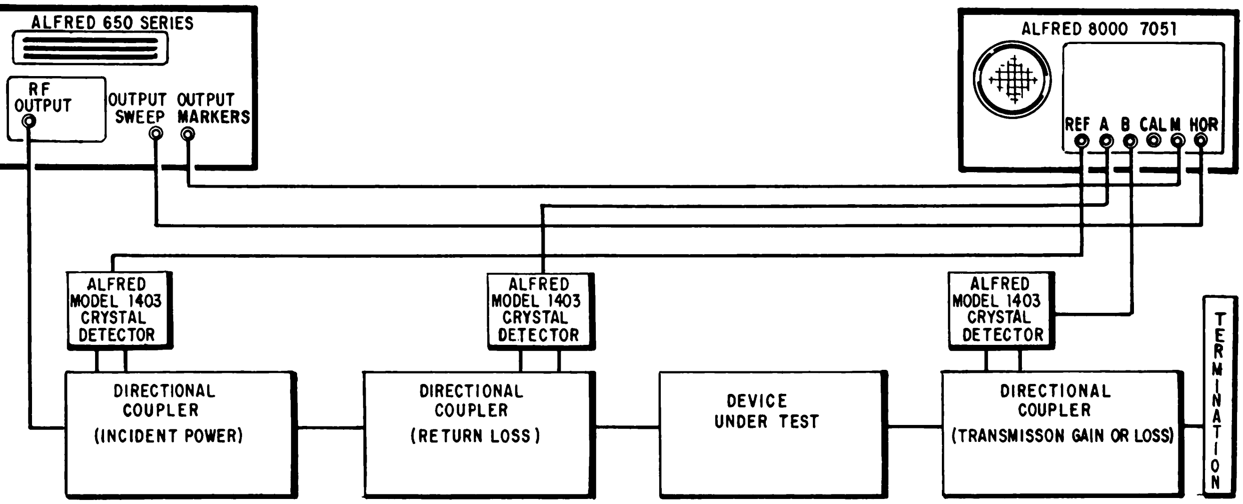
FDR identifies defective systems by using
ertion-loss (attenuation in the line) and re-
-loss (voltage standing wave ratio (VSWR))
asurements to classify the system as good
in need of repair. These measurements are
de with the test setup shown in figure 5-30.
h a test configuration provides simultaneous
asurement of both return loss and insertion
s (or gain) of passive (or active) devices.

If the input and output connectors are acces-
le, an insertion-loss check verifies input-to-
put performance across the band. For inser-
-loss measurement, the network analyzer
ing its B and REF channels) indicates the ratio
utput to input directly in db. For tests of long
les whose ends are accessible, the system
ws measurements from a connector end as
as 2,000 feet from the test setup. In some
tems, however, either the input or the output
nector, such as a cable to a distant super-
ucture point in a plane or missile, may be
ccessible. For such systems, a return-loss
asurement made on the accessible connector
l provide a total system check. In TR or high-
n systems in which an active device isolates
input and output, a return-loss check can be made from each end. Another useful application of return-loss measurement occurs when the cable feeds the output of a high-power microwave tube which can be destroyed by excessive reflected energy. For return-loss measurements, the network analyzer (using the A and REF channels) indicates the ratio of reflected power to incident power directly in db. As shown in figure 5-30, the signals in each case are sampled by directional couplers.

Comparison of each measured signal with the incident power supplies automatic compensation for any swept-source power variations across the band, giving a true graph of performance in db versus frequency on the network analyzer CRT. To provide measurement capability for long cable systems having high losses, the instrument furnishes direct db readout over a 60-db dynamic range.

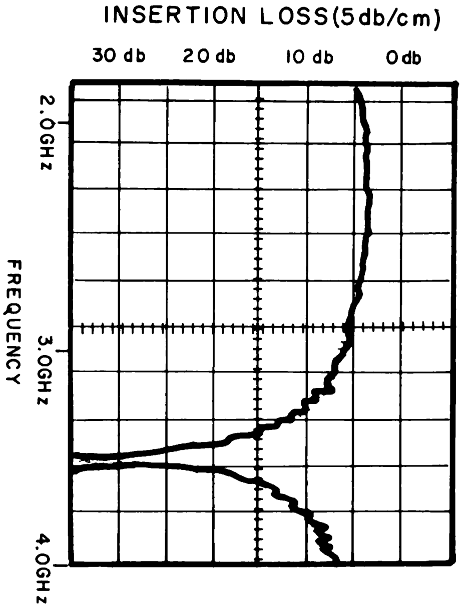
An example of insertion-loss measurement is given in figure 5-31. In this example a loss of less than 10 db is acceptable. The cable, however, needs repair because a fault which produces an insertion loss greater than 35 db at a frequency of 3.56 GHz is present.

An example of a return-loss measurement for the same cable is shown in figure 5-32. Here, a loss of 11 db, which corresponds to a VSWR of less than 1.8, is acceptable. At 3.56 GHz, then, the return loss is equal to 5 db, which corresponds to a VSWR of 3.6.


ALFRED 650 SERIES
RF OUTPUT
OUTPUT SWEEP
OUTPUT MARKERS
ALFRED 8000 7051
REF
A
B
CAL
M
HOR
ALFRED MODEL 1403 CRYSTAL DETECTOR
ALFRED MODEL 1403 CRYSTAL DETECTOR
ALFRED MODEL 1403 CRYSTAL DETECTOR
DIRECTIONAL COUPLER (INCIDENT POWER)
DIRECTIONAL COUPLER (RETURN LOSS)
DEVICE UNDER TEST
DIRECTIONAL COUPLER (TRANSMISSON GAIN OR LOSS)
TERMINATION

AT. 419

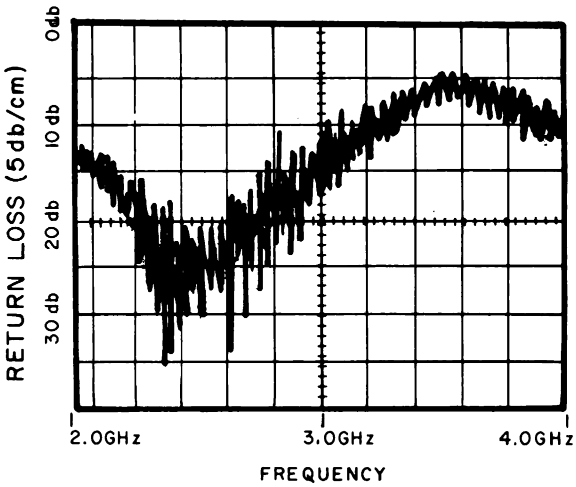
Figure 5-30.—Test setup for VSWR and insertion performance.



AT.420
Figure 5-31.—Insertion-loss display.

The dual-channel network analyzer permits display of both measurements simultaneously when the complete test setup shown in figure 5-30 is used.

For cable-length and fault-location measurements, a waveguide or coaxial tee is incorporated in the test setup (fig. 5-33); the system is calibrated with the calibration cable, and then the cable under test is connected to the tee. (The calibration referred to in this paragraph is an operator adjustment, not a calibration to be performed by a metrology activity.) The resultant CRT display on the network analyzer consists of a stationary pattern containing a series of "half-dome ripples." A count of the total number of these ripples indicates the number of feet from the cable end to the fault, as illustrated in figure 5-34. The FDR display is from the cable system which produced the "needs repair" indications in figures 5-31 and 5-32. Multiplying the 5 2/3 ripples which appear on the oscilloscope by the display calibration factor of 2 feet per ripple will quickly identify the location of the fault (11 1/3 feet from the cable-end connector). Figure 5-35 illustrates a dual-channel display after faults (figs. 5-31 and 5-32) have been corrected. The insertion loss is less than 10 db and the return loss greater than 11 db, indicating that performance is now satisfactory.

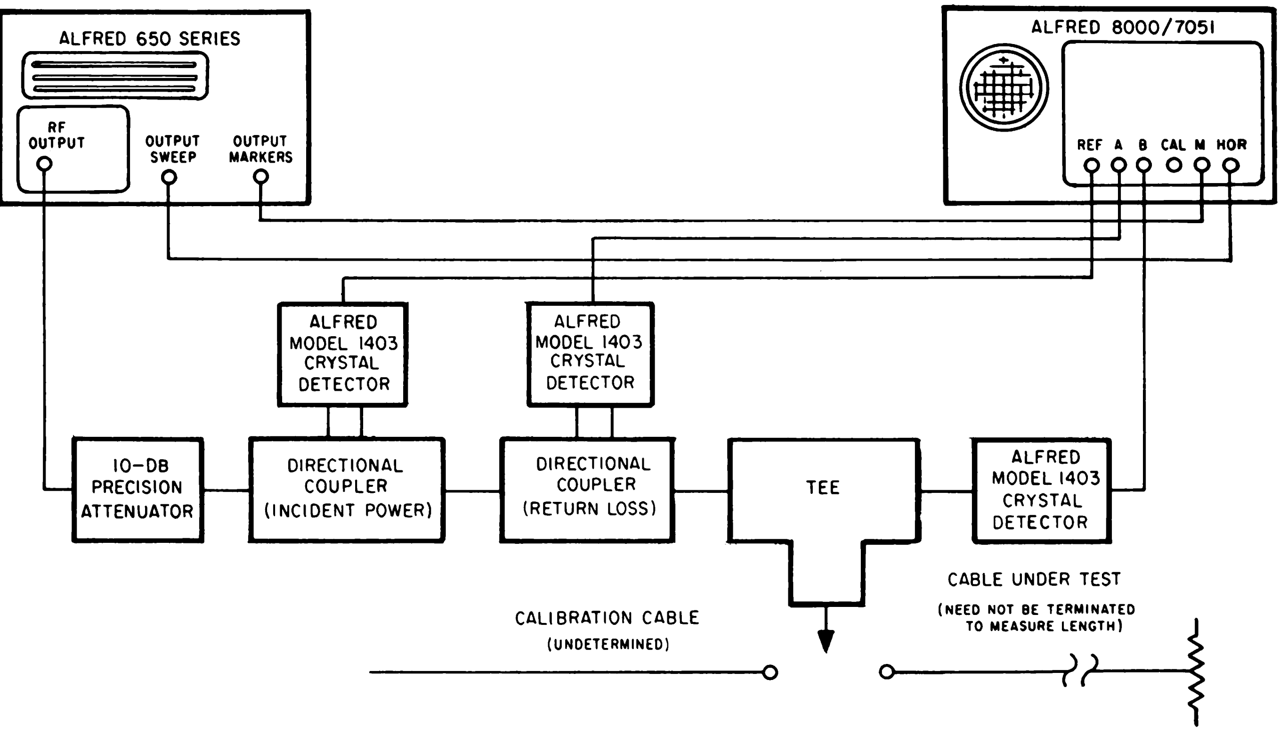


AT. 421
Figure 5-32.—Return-loss display.

Detailed FDR Analysis

With the sweep oscillator output, the transmission system under test, and the crystal detector all connected to the same tee junction, discontinuities and/or termination mismatch in the system reflect some of the incident power. The reflected power combines with the incident signal at the crystal detector, resulting in a changing phase relationship that depens upon both distance to the discontinuity and signal frequency. As the frequency is swept, it changes the number of wavelengths which occupy the fixed path from the tee to the point of reflection and back. The display thus will show amplitude "ripples" which result from the summing of the incident and reflected signals whose relationship changes with frequency. Figure 5-36 illustrates how the magnitude of the vector sum of these signals, which is the signal level detected for display, varies with frequency.

The resultant display of the varying-magnitude detected signal is actually a logarithmic SWR presentation. The ripple peaks are adjacent VSWR maxima which occur, during the sweep, at each frequency in which the "round-trip" length of the reflected wave path from the source to the defect has changed by one wavelength. The number of ripples appearing across the full width of the display (which is inversely proportional to


ALFRED 650 SERIES
RF OUTPUT
OUTPUT SWEEP
OUTPUT MARKERS
ALFRED 8000/7051
REF
A
B
CAL
M
HOR
ALFRED MODEL 1403 CRYSTAL DETECTOR
ALFRED MODEL 1403 CRYSTAL DETECTOR
10-DB PRECISION ATTENUATOR
DIRECTIONAL COUPLER (INCIDENT POWER)
DIRECTIONAL COUPLER (RETURN LOSS)
TEE
ALFRED MODEL 1403 CRYSTAL DETECTOR
CABLE UNDER TEST
(NEED NOT BE TERMINATED TO MEASURE LENGTH)
CALIBRATION CABLE
(UNDETERMINED)

AT. 422

Figure 5-33.—Test setup for fault-location measurement.

he frequency separation of adjacent ripples) is measure of the distance from the discontinuity o the crystal detector. Therefore, direct readut of fault distance is provided when the swept ource is operated over a sweep width (ΔF) which s chosen to provide a display calibration (in erms of ripples per foot) compatible with the ength of the transmission system under test.

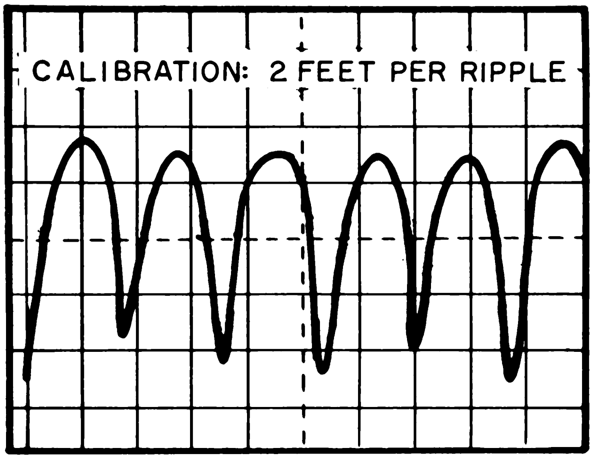
In a coaxial system, it can be shown that the istance to a discontinuity, which may be a fault r the cable end, is represented by the equation

$$D = \frac{492\ K\ N}{\Delta F}$$

here D is the distance to the fault or cable end n feet; 492 is the half wavelength in feet of a 1-Hz wave in free space transmission; K is the ropagation constant which relates the propagaion velocity in the coaxial system to the velocity n free space; N is the number of ripples oberved in the display; and ΔF is the swept-freuency excursion (sweep width) of the signal source in MHz. Note that for any type of cable, F can be selected to equal 492K, so that the distance in feet is equal to the number of ripples (including the fractional ripples) shown in the display. In waveguide systems, the distance down the waveguide to the fault is represented by the same equation, with K denoting the relation $\frac{\lambda}{\lambda g}$ (λ is the wavelength in free space and λg is the wavelength in the waveguide) at the frequency of measurement.

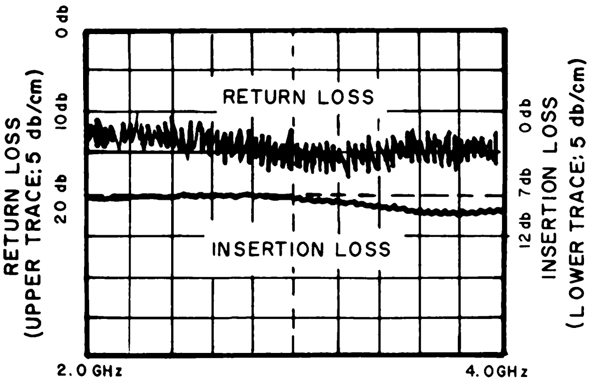
Cable Measurements

The test setup in figure 5-33 shows that the only variable requiring adjustment is the sweep width ΔF. To calibrate the display in terms of feet per ripple, it is most convenient to select a ratio of 1:1 or an integer factor give a reasonable pattern for the length of system being measured, such as 1 foot per ripple for a 20-foot cable and 5 feet per ripple for a 100-foot cable. The simplest way to adjust ΔF is to use a known-length "calibration cable" having the



AT. 423
Figure 5-34.—Measuring a cable fault.

same propagation constant as the cable to be tested. For example, if a 10-foot length of cable is used as a calibration cable, a sweep-width adjustment which gives a 10-ripple display calibrates the CRT readout to 1 foot per ripple. A ΔF setting producing five ripples places calibration at 2 feet per ripple and a ΔF setting producing two ripples result in a calibration of 5 feet per ripple (fig. 5-37).



AT. 424
Figure 5-35.—Dual-channel display of a repaired cable.

The calibration cable is a simple device for checking the setting of ΔF. In figure 5-37, the 1-foot-per-ripple, 2-foot-per-ripple, and 5-foot-per-ripple calibrations require ΔF settings of 324 MHz, 162 MHz, and 64.8 MHz, respectively, for a cable with a propagation constant of 0.659. The ΔF sweep width could also be set with a cavity wavemeter.

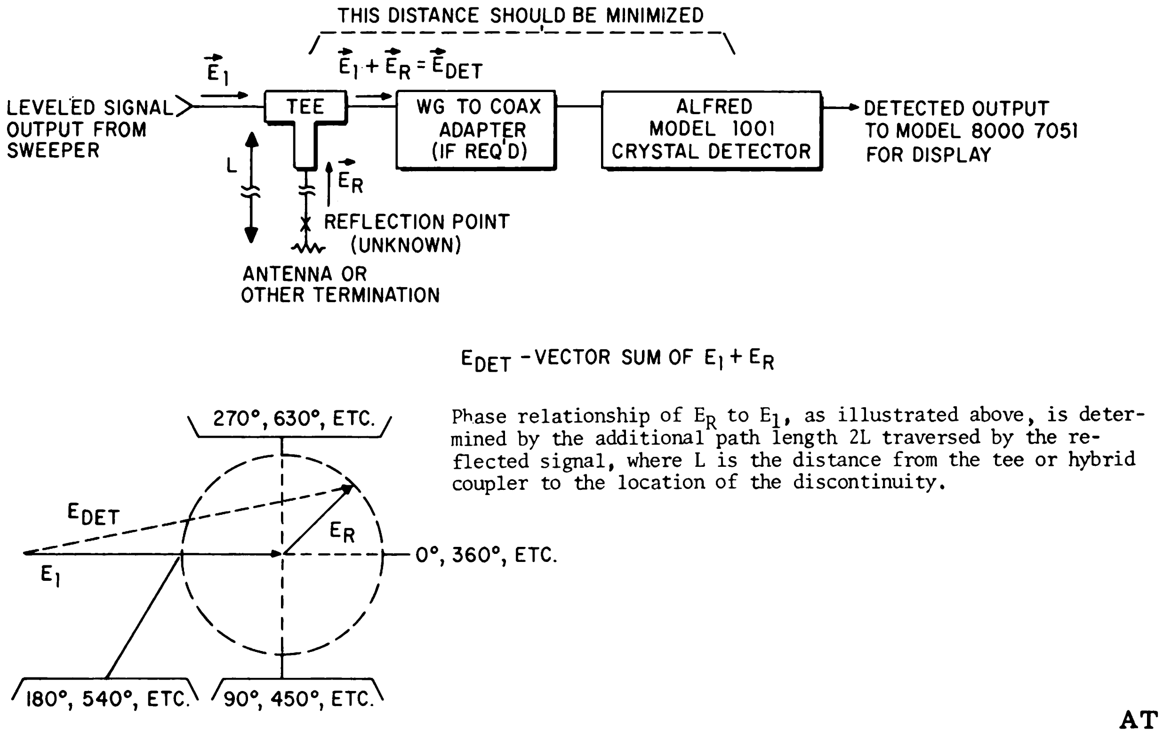
Once ΔF is set, the instruments can make an unlimited number of measurements without readjustment. In testing a variety of cables having different propagation constants, it is unnecessary to readjust ΔF.

Instead, the observed quantity of ripples can be multiplied by the quotient derived from dividing the propagation constants (the new propagation constant divided by a calibration propagation constant). The FDR display shown in figure 5-38, obtained from a 4-foot, 4-inch cable that has a propagation constant of 0.659 is connected to a 96-foot air dielectric cable (unterminated) having a different characteristic impedance and a propagation constant of 0.84. With a calibration cable having a propagation constant of 0.659, the display is calibrated to provide readout of 2 feet per ripple. The display shows a 39-ripple pattern resulting from the discontinuity at the distant open end superimposed on a two-ripple pattern and the 2-foot-per-ripple calibration factor is the distance to the mismatched connection. The 39-ripple pattern multiplied by $\frac{0.84}{0.659}$ converts the readout to 50 ripples, which, when multiplied by the 2-foot-per-ripple calibration factor, gives the total which equals the 100-foot distance to the end of the cable run.

After the FDR setup is calibrated, the unknown cable is connected to the measurement tee. A count of the number of ripple cycles in the display is an accurate measure to the cable end or any fault in terms of the foot-per-ripple calibration. A partial ripple cycle indicates a corresponding fraction of that calibration.

Applications

The speed and simplicity of the FDR measurement can be illustrated with a few examples. Figure 5-39 is an FDR display of a 32-foot, 4-inch length of good RG-58/U unterminated coaxial cable. There are 16 1/4 observed ripples multiplied by the 2-foot-per-ripple calibration, resulting in a readout of 32 feet, 6 inches as the distance to the mismated cable end. (Accuracy is usually better than 5 percent.)

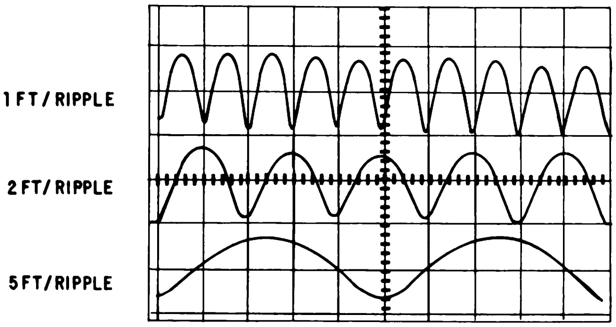

THIS DISTANCE SHOULD BE MINIMIZED
$\vec{E}_1$
$\vec{E}_1 + \vec{E}_R = \vec{E}_{DET}$
LEVELED SIGNAL OUTPUT FROM SWEEPER
TEE
WG TO COAX ADAPTER (IF REQ'D)
ALFRED MODEL 1001 CRYSTAL DETECTOR
DETECTED OUTPUT TO MODEL 8000 7051 FOR DISPLAY
L
$\vec{E}_R$
REFLECTION POINT (UNKNOWN)
ANTENNA OR OTHER TERMINATION
E_{DET} - VECTOR SUM OF $E_1 + E_R$
270°, 630°, ETC.
E_{DET}
E_R
E_1
0°, 360°, ETC.
180°, 540°, ETC.
90°, 450°, ETC.

Phase relationship of E_R to E_1, as illustrated above, is determined by the additional path length 2L traversed by the reflected signal, where L is the distance from the tee or hybrid coupler to the location of the discontinuity.

AT. 425

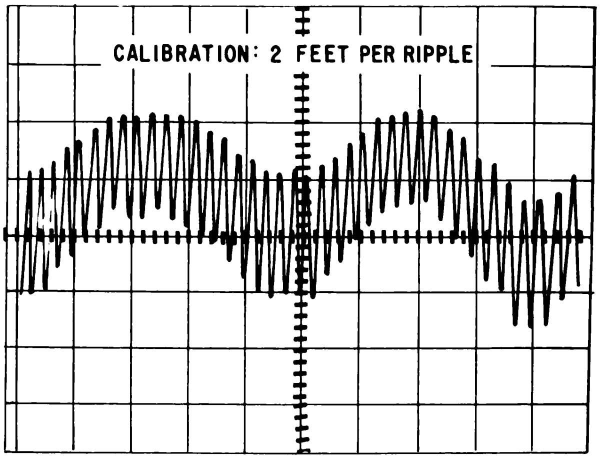
Figure 5-36.—Magnitude of the vector sum.

Figure 5-40 shows how the pattern changes when the same cable has one or more discontinuities. In the figure a fault-producing crimp is located 8 feet from the measurement end. A pattern consisting of 16 (and a fraction) ripples (indicating the discontinuity of the open end) is



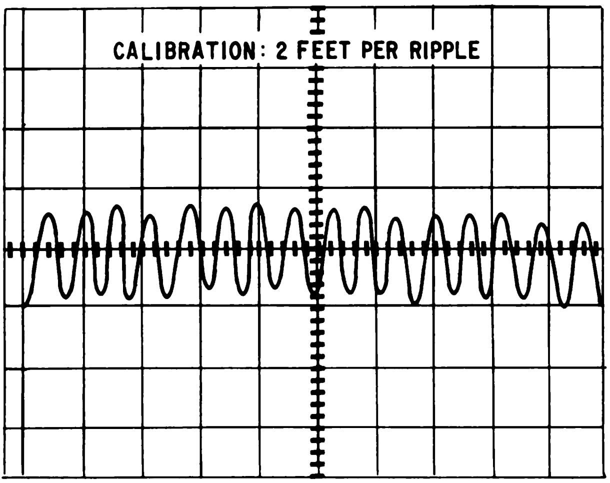
AT. 426

Figure 5-37.—Tripple calibration displays.



AT. 427

Figure 5-38.—A 4-foot, 4-inch cable connected to a 96-foot air dielectric cable.

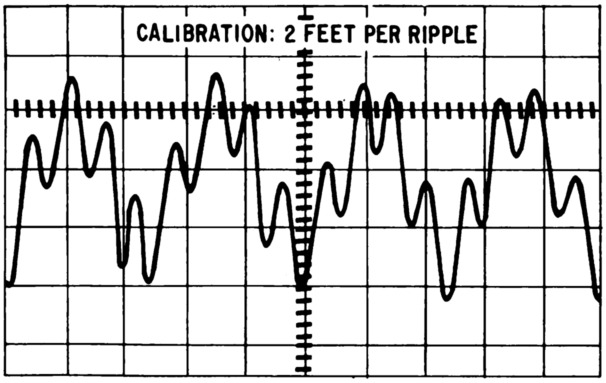


AT.428

Figure 5-39.—Length of good RG-58/U coaxial cable.

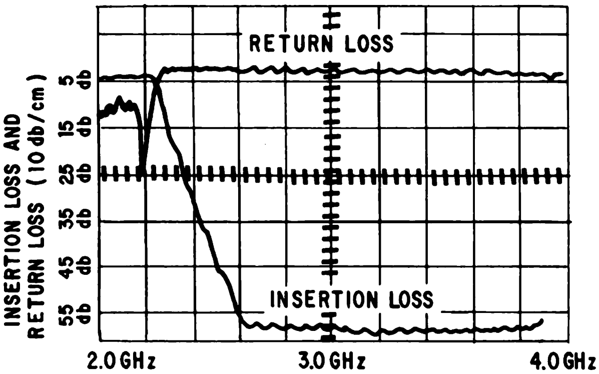
superimposed on a four-ripple pattern (verifying the fault at the 8-foot point).

Figure 5-41 illustrates the performance (insertion and return loss) checkout display obtained from an unterminated transmission cable system which has a 2.5-GHz filter between two equal lengths of cable. This figure also shows the response from a system having a frequency-sensitive discontinuity. The insertion-loss and return-loss displays indicate some discontinuity in the system.



AT. 429

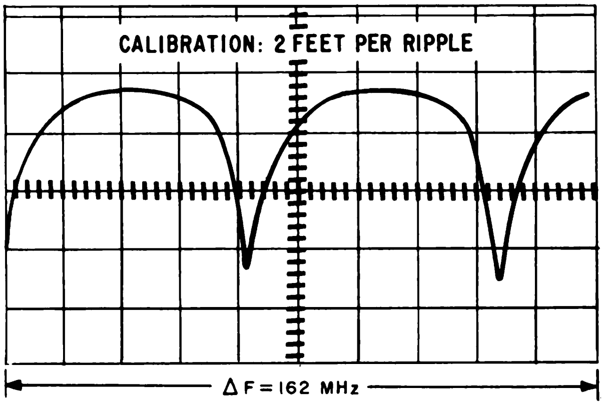
Figure 5-40.—Length of crimped RG-58/U coaxial cable.



AT. 430

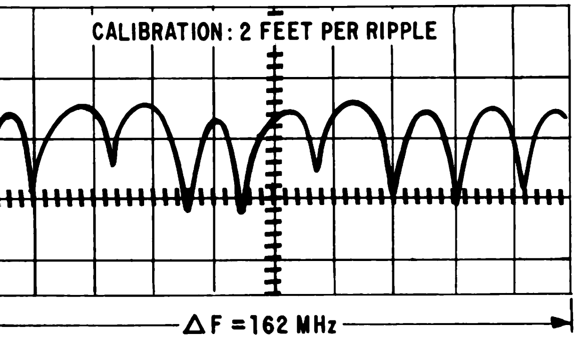
Figure 5-41.—Cable containing a 2.15-GHz filter.

The FDR display (fig. 5-42) locates it precisely. Remember the cable has a 2.15-GHz low-pass filter in the middle of its run. TDR normally would indicate the filter as a fault, with FDR, however, the cable out to the filter can be checked with frequencies above 2.15-GHz. A frequency of 2.6 GHz, well above filter cutoff, was used for the FDR display shown in figure 5-42. If a calibration factor of 2 feet per ripple is used, the displayed 2 1/3 ripples indicate the filter is at a point 4 2/3 feet along the cable. The far end of the cable from the filter to the antenna can be checked with frequencies below 2.15 GHz, as shown in figure 5-43.



AT. 431

Figure 5-42.—Insertion above filter frequency, 2.6 GHz.



AT. 432

ure 5-43.—Insertion below filter frequency, 2.1 GHz.

Figure 5-43 is an FDR display of the same le system used for the displays shown in fig- es 5-41 and 5-42. With an insertion frequency 2.1 GHz, which is below the low-pass filter toff, the display of 8 2/3 ripples shows that open-end discontinuity is 17 1/3 feet away. te that the short skirt on two of the ripples ncides with the two-ripple peaks in figure 42. This indicates a slight mismatch at the er interface below cutoff, characterized by return-loss trace at the left-hand edge of ure 5-41.

nclusion

To locate faults and to indicate their serious- ss, FDR uses the comprehensive frequency- nsitive information contained in the SWR dis- y, thus making a difficult measurement nple. In addition to providing positive identifi- ion of all faults at the frequency of operation, new system makes possible efficient semi- tomatic routine testing of all cables in a com- x aircraft.

FDR, because of its technical advantage, adds the Navy's maintenance techniques and results additional savings in manpower and materials. FDR is not only used in aircraft but can also applied to naval surface ships, submarines, certain shore installations.

SPECIAL AVIONICS SUPPORT EQUIPMENT

SACE (A-6)

The complexity of the electronic systems today has necessitated the development of special avionics support equipment and the adoption of specific maintenance methods in order to maintain aircraft availability and effectiveness at a reasonable level.

Responsibility for quickly getting the aircraft "up" and available rests, first of all, at the organizational maintenance level. The aircraft is repaired at the organizational maintenance level by locating and replacing the defective aircraft replaceable assembly (ARA).

The defective ARA is forwarded to an intermediate level shop which has the responsibility for repairing and/or adjusting the ARA and returning it to supply as a ready for issue (RFI) item. If the defective ARA belongs to the group of equipments which do not lend themselves to automatic testing, it should be "substituted" into a test-bench harness and analyzed down to the module and/or component level by using more or less conventional test equipment. However, if the defective ARA belongs to one of the equipments or systems which can be checked with SACE (Semiautomatic Checkout Equipment), it will be connected to the corresponding SACE adapter console and automatically fault isolated to the module level.

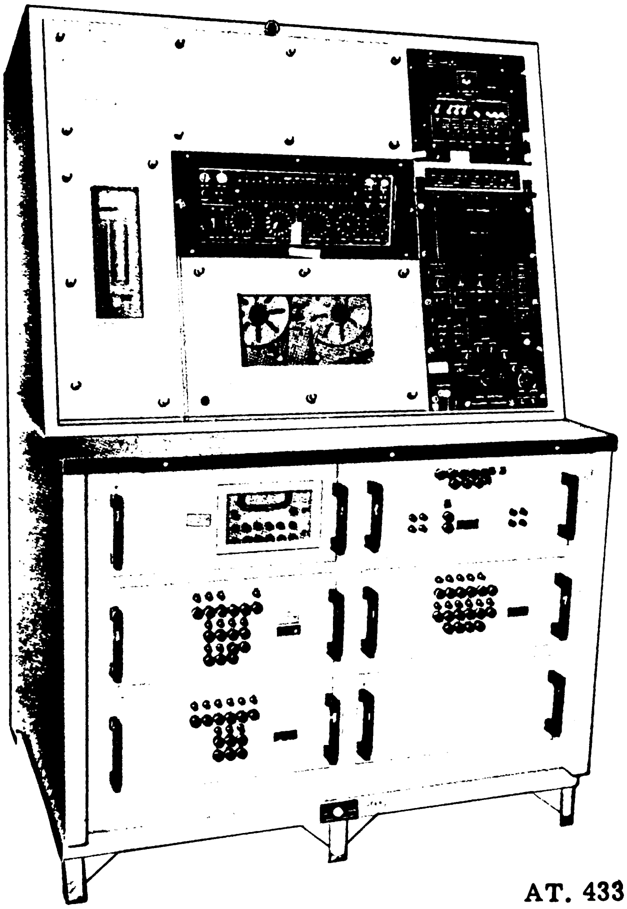
When defective modules are located, they are immediately replaced and the ARA is ready for service.

The defective module moves on to the module repair area where it is fault isolated to the component level with a special test set. The special module test sets are not computer controlled and are, therefore, not part of SACE.

SACE Shop

The operation of a SACE shop is controlled by a programer comparator (fig. 5-44).

After the technician has connected the defectitve ARA to the appropriate SACE adapter test console (which, in turn, is connected to the programer comparator), he selects the correct programer comparator tape and inserts it into the programer comparator. Testing begins when the start button is pressed. The tests are performed automatically and continuously by the test console and will stop only for special instructions or when a defective module is located.



AT. 433

Figure 5-44.—Programer comparator.

Programer analyzer test consoles are provided to test the programer comparator. Figure 5-45 displays a programer analyzer test console.

VAST (S-3, F-14, A-7)

VAST (Versatile Avionics Shop Test) is the Navy's newest attempt to improve avionics maintenance and quicken turnaround time for avionics black boxes.

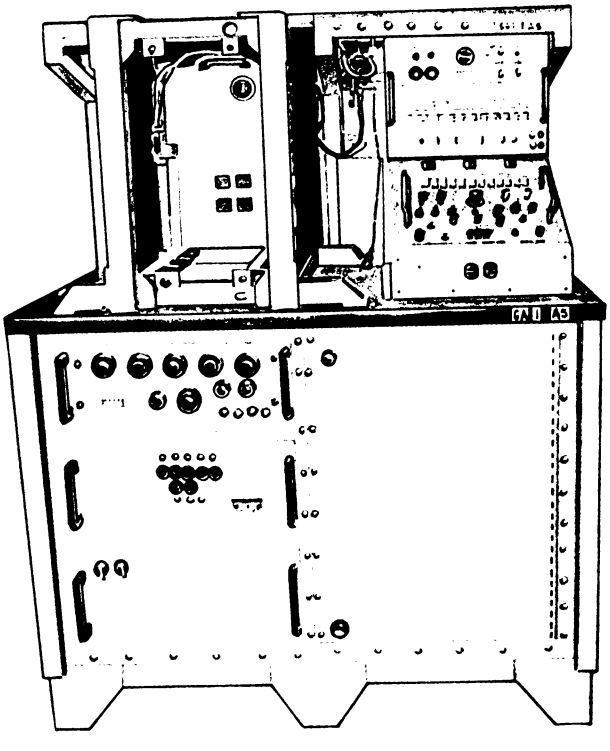
The VAST system, officially designated the AN/USM-247, will be installed in attack aircraft carriers (CVA) and at major shore installations. VAST will be able to handle the testing and troubleshooting of 85 percent of the Navy's future avionic systems; the remainder, involving such items as inertial and hydraulic devices and radiating portions of radar and infrared systems, will still require special test facilities.

Where circumstances do not readily permit each ARA to be designed to be directly compatible with VAST, interface transformation units may be approved. In its simplest form, an interface transformation unit (ITU) may be merely a test cable which adapts the VAST connector to the assembly connector. More complex ITU's may require passive elements, active elements, and even programable circuitry.

Avionic contractors must develop three types of test programs for each assembly which are compatible with the AN/USM-247. These include the following:

1. Overall (end to end) test, to determine whether an assembly (ARA) is operating properly.
2. Module isolation test, to enable a fault to be traced to a replaceable module within the assembly.
3. Fault isolation test, to permit malfunction to be traced to lowest repairable level within a module.

The avionic contractor's first step in preparing the software for use by VAST will be to prepare a diagnostic flow chart. Next, diagrams, showing which of the available VAST building blocks are necessary for each test and the interface transformation unit requirements, must be prepared. The test diagrams must contain



AT. 434

Figure 5-45.—Programer analyzer console.

special instructions for mode of operation, floating ground points, shielding, test points, pin connections, and functional input/output requirements.

Finally, the avionic contractor must write an English language program (ELP) on a special form. This lists such things as a functional description of each test, the stimulus level with acceptable tolerance, the allowable limits for satisfactory performance, and the next test to be performed, depending upon the results of the current test.

This contractor written ELP is then sent to a VAST programing center for conversion into the language used by VAST.

VAST is designed for use with a general purpose digital computer. A single computer can serve as many as six individual test stations simultaneously on a time-share basis. Normally, only three test stations will share a single computer to enable each to operate as if it were the sole computer user.

VAST can operate in an automatic mode in which the computer runs through a sequence of tests rapidly and stops only when it finds a malfunction; or, it can be operated in a manual mode in which the human operator selects the test to be conducted if he has a clue as to the nature of the fault.

VAST is also designed to perform self-test operations to check that all units are operational. If it detects a malfunction, VAST is able to isolate the malfunction to one of its basic building blocks and then trace the fault to the defective module.

CHAPTER 6

ANTENNAS AND PROPAGATION

The fundamental concepts of propagation and antennas are included in Basic Electronics, NavPers 10087-C, Vol. 1. This chapter is an extension of these concepts and includes sections on antenna arrays and typical airborne antennas. The objective of this chapter is to more fully acquaint the AT with the mechanics of propagation, the results of irregularities in the atmosphere, the consideration required in the selection of the proper frequency for specific purposes, and the operational characteristics of the various types of antennas and arrays.

In the study of this chapter, it should be kept in mind that the subject matter field is broad and no attempt at complete coverage is made. Rather, only such background information as will be of help to the AT is included. As an Aviation Electronics Technician First Class or Chief, you will be required to supervise and instruct others in the maintenance of antennas and antenna systems. Therefore, it is essential that you have a knowledge of radio wave propagation as well as a knowledge of antenna principles and their application in aviation electronics equipment.

PROPAGATION OF RADIO WAVES

ELECTROMAGNETIC FIELDS IN SPACE

At best, any device that is used to picture electromagnetic radiations in space is only a crude analogy of what is actually taking place. Although electromagnetic radiations are commonly considered to be waves, under certain circumstances they behave in ways that make them appear to have some of the properties of particles.

Wavefronts

In general, it is easier to picture electromagnetic radiations in space as being composed of horizontal and vertical lines of force. These lines of force are made up of a magnetic (H) and an electric (E) component, and together make up the electromagnetic field in space. Strong fields are represented by many lines closely spaced; whereas, weaker fields are represented by fewer lines more widely spaced.

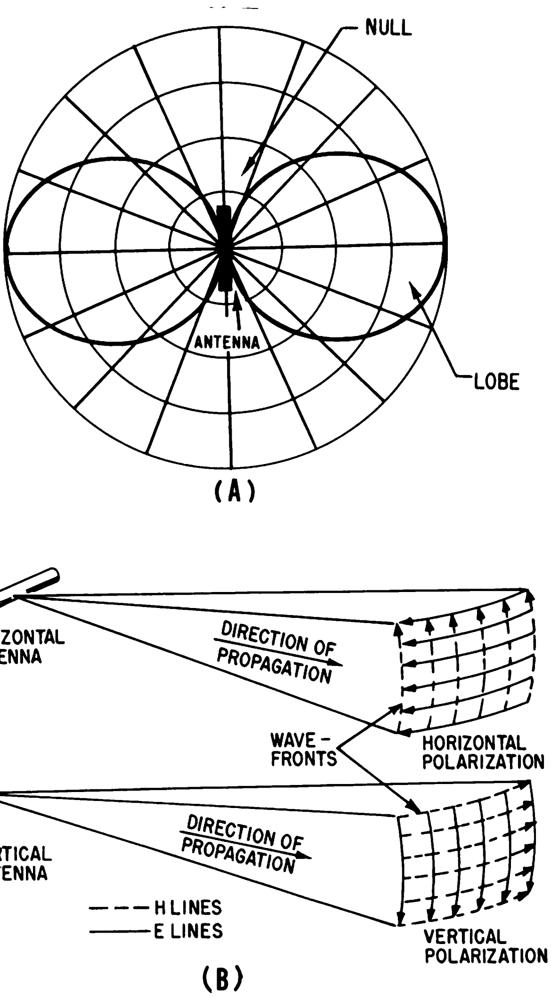
The E- and H-fields are mutually perpendicular to each other and to the direction of travel. These fields, traveling through space together, form a radio wave. The frequency of the radio wave is the same as the frequency of the RF current which produced it. Radio waves are radiated into space at the speed of light, 186,000 miles (or 300,000,000 meters) per second. The velocity is constant, regardless of frequency. Because of this constant velocity, it is possible to establish the relationship between the frequency and the wavelength. This relationship is expressed as

$$\lambda = \frac{300}{f} \quad \text{or} \quad f = \frac{300}{\lambda}$$

where λ is the wavelength in meters, f is the frequency in megahertz, and 300 is the velocity of travel in millions of meters per second.

Energy from the transmitting antenna moves outward in ever-expanding spheres. A small portion of one of these spheres is called a WAVEFRONT. As indicated in figure 6-1 (B), the H-lines are perpendicular to the E-lines, and both are perpendicular to the direction of propagation.

HORIZONTAL POLARIZATION means that the electric lines are horizontal with respect to the earth, and VERTICAL POLARIZATION means that the electric lines are vertical with



AT.435

gure 6-1.—Antenna radiation. (A) Radiation pattern; (B) wavefronts.

spect to the earth. The choice of the electric ld as a reference field results from the ctice of measuring radio wave intensity in ms of electric field intensity (for example, crovolts per meter).

ectivity

When considering the energy radiated from antenna, an important concept is the DIREC-VITY of the antenna. The directivity of an enna is a measure of its ability to radiate energy in the desired direction (or directions) and to suppress the radiation in other directions. The same is true of a receiving antenna; in this case, signals from the favored direction (or directions) are received more easily than those from other directions.

The RADIATION PATTERN, which is a good indication of the directivity of an antenna or antenna array, is usually plotted on polar graph paper. It should be emphasized that when polar coordinates are used, the resulting curve is NOT an actual picture or outline of the energy radiated by the antenna. It is rather an indication of the relative amount of energy delivered to points on an imaginary circle a certain distance from the antenna, which is usually located at the center. The points where the measurements are taken are usually spaced 10° or more apart. Thus, the polar plot is a good picture in two dimensions of the directivity of the antenna. (See fig. 6-1 (A).)

It should be emphasized also that the pattern is three dimensional, although the plot is commonly given only in the horizontal or vertical plane. The rounded projections of the polar pattern are called LOBES and the indented portions, representing minimum energy pickup in the test antenna, are called NULLS.

Reflection

When considering the movement of electromagnetic fields through space, it is very important to understand clearly what is meant by reflection, refraction, and diffraction. Because radio waves of short wavelengths act somewhat like light waves (both of which are electromagnetic radiations), it is well to consider these effects from the point of view of light waves, which may be more readily observed.

A basic coverage of the reflection and refraction of light is presented in chapter 5 of Aviation Electronics Technician 3 & 2, NavPers 10317-D. A review of these principles will be of great help in understanding the action of radio waves in space.

Reflection takes place only when the reflecting surface is large compared to one-half the wavelength of the incident wave, and smooth for an appreciable portion of one-half wavelength. Under these circumstances, the angle of incidence is equal to the angle of reflection. When these conditions are not met, scattering will occur. Scattering is a common occurrence. As a matter of fact, FORWARD SCATTER of radio waves in the troposphere and ionosphere (because of irregularities in density) is an important method of radio wave propagation.

Refraction

When a light ray passes at an angle from a less dense to a more dense medium, it is bent toward the normal; in other words, the angle of refraction is less than the angle of incidence. Likewise, when a light ray passes from a more dense to a less dense medium, it is bent away from the normal; in other words, the angle of refraction is greater than the angle of incidence. Both of the conditions are shown in figure 6-2 (A).

The INDEX OF REFRACTION is a term used to describe how much bending will take place as electromagnetic waves pass through a given substance. The higher the index of refraction, the more the bending. The index of refraction is the ratio of the velocity of light waves in a vacuum to the velocity of light in the substance being considered.

In the case of radio waves being refracted in the ionosphere, the path is gradually curved because there is no sharp point of transition between layers of different densities. Those rays that make a large angle with respect to the horizontal along the earth may be refracted a small amount and pass on through the ionosphere to outer space; those that make a smaller angle will travel a greater distance in the ionosphere and may be bent to such an extent that they will return to earth. The net result is as if the wave had been REFLECTED back to earth. A simplified illustration of ionospheric refraction is given in figure 6-2 (B). A certain amount of refraction also takes place in the troposphere (below the ionosphere) because of the proximity of warm and cold air masses.

Diffraction

Diffraction of light occurs when a beam of light passes over the edge of an opaque object. The energy is bent, or diffracted, around the edge of the object, as indicated in figure 6-3. Instead of a sharp outline being formed, the shadow will be blurred because of the bending of the light around the object. Red light (long wavelength) is bent into the shadow more than violet (short wavelength).

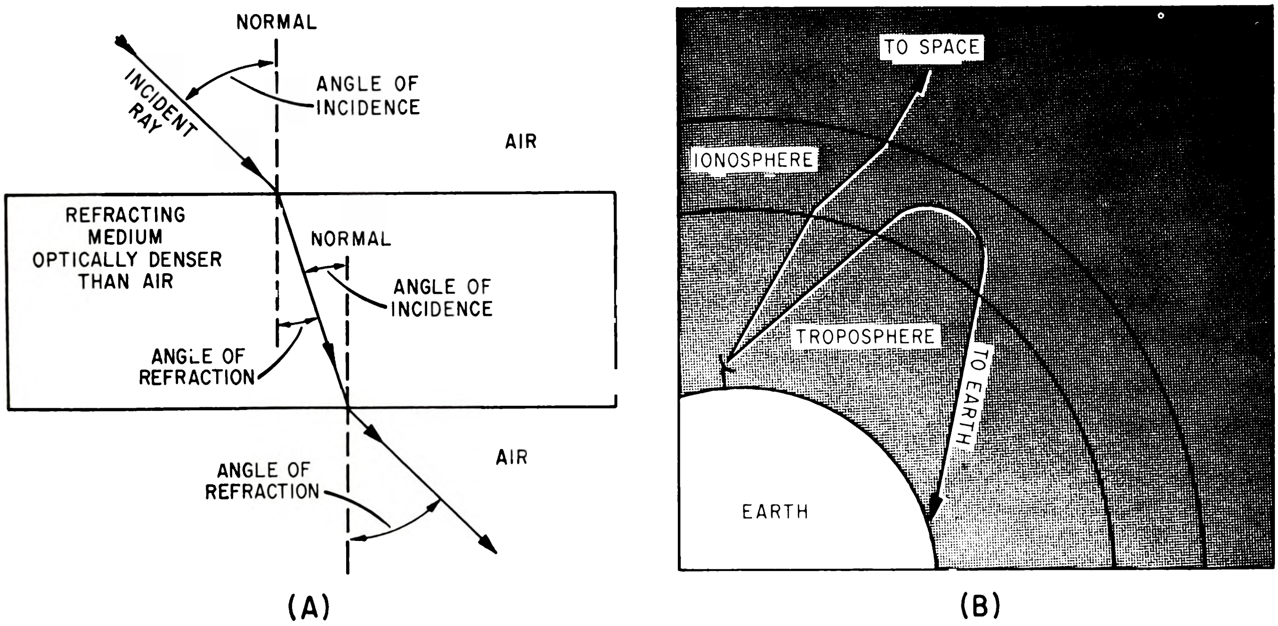


Figure 6-2.—(A) Refraction of light; (B) refraction in ionosphere.

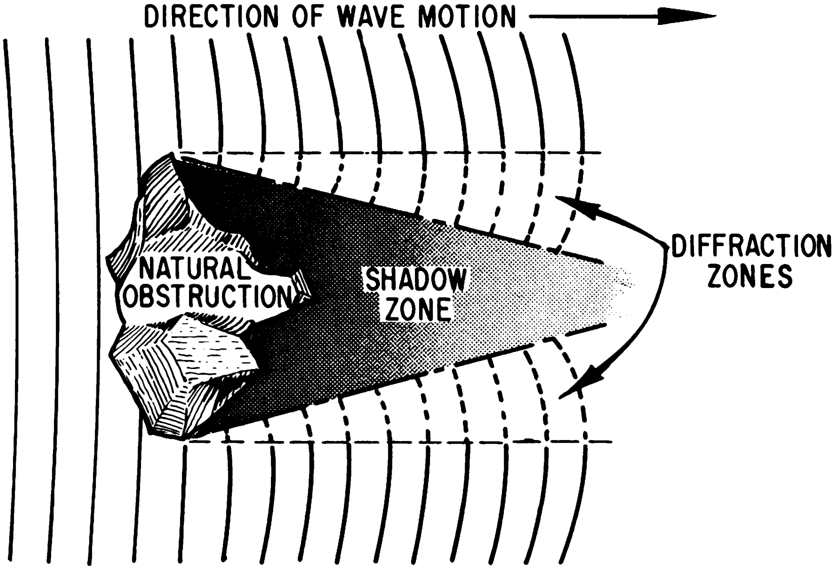


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Figure 6-3.—Diffraction.

Low frequency radio waves bend around natural obstructions, such as mountains, in much the same way that light does. At the higher frequencies, the bending is much less apparent.

Absorption

Another natural phenomenon which affects propagation is absorption. Absorption is the using up of radiated energy by the medium the energy is passing through.

Absorption will not occur in a vacuum, however when the radiated energy passes through water vapor or atmospheric gases such as oxgen, absorption can be high. Liquid water (rain, heavy clouds) is especially absorptive.

Atmospheric absorption is slight for VHF, but long range UHF absorption is significant. Absorption attenuation is not a function of distance; but the loss is a constant for a given distance. For example, if a radio wave is to travel 50 miles and the absorption in the first ten miles is 3 milliwatts, the absorption in each succeeding ten miles would also be 3 milliwatts or a total of 15 milliwatts. Thus, absorption is measureable in wattage loss per mile.

Ionospheric absorption can be high in the HF and the VHF ranges, while frequencies above the low UHF range penetrate this layer and are not affected. Ranges below HF do not penetrate the ionosphere (for all practical purposes) but are reflected.

Where absorption takes place, thermal noise is generated. Thus, a highly absorbent media can render a sensitive receiver almost useless due to both absorption and noise.

Although these effects (reflection, refraction, diffraction, and absorption) have been listed separately, it is not uncommon for them to occur simultaneously. In addition, there are other factors, such as changes in polarization and reinforcement or cancellation due to variations in signal path lengths. Therefore, it is frequently difficult to discover exactly what has happened to the radio wave during its passage from the transmitter to the receiver.

Forward Scatter of Radio Waves

Much research is being conducted at present to determine the practical use to which the phenomenon of FORWARD SCATTER may be put.

Forward scatter is believed to be due to small variations in the composition of the atmosphere. This lack of homogeneity may be created by such irregularities as the ionization left by meteor trails, ionospheric winds, auroral effects, tropospheric turbulence, variation of the refractive index, etc. The net effect is a scattering of radio waves in all directions, especially in the forward direction of travel. By the use of powerful transmitters, highly directional antennas, and high gain receivers, scatter signals from the troposphere may be received up to 600 miles and scatter signals from the ionosphere may be received at distances of 600 to 1,200 miles. For tropospheric scatter, frequencies between 100 MHz and 10,000 MHz have been used; for ionospheric scatter, frequencies between 25 MHz and 60 MHz have been used.

Although much work remains to be done in this field, it seems probable that VHF frequencies will become increasingly important in long range communications. For ranges up to 600 miles where tropospheric scatter is effective, the useful frequency range probably will be greatly extended.

IONOSPHERIC VARIATIONS

Variations in the ionosphere greatly affect the propagation of certain radio waves. It is therefore necessary to include a brief treatment of the variations that take place in the ionosphere. Although a degree of irregularity is characteristic of all ionospheric variations, nevertheless it is convenient to subdivide them into both irregular and regular variations.

Irregular variations cannot be accurately predicted in advance; regular variations follow a general pattern, and therfore may be predicted with some degree of accuracy.

Certain basic information on the ionosphere is given in Basic Electronics, NavPers 10087-C and should be reviewed at this point.

Irregular Ionospheric Variations

SUDDEN IONOSPHERIC DISTURBANCE.—This type of disturbance in the ionosphere is caused by radiation from solar flares that produce intense ionization in all layers of the ionosphere in daylight areas.

Frequencies above 1 or 2 MHz (depending on the intensity of ionization) are largely absorbed in the D layer. Higher frequencies may be used for short distance communications, and lower frequencies (which do not penetrate the D layer) may be used for long distance communications.

IONOSPHERIC STORMS.—These magnetic disturbances occur about 18 hours after solar flares. The upper ionosphere expands and becomes diffused, the effects being more severe near the poles and less severe near the Equator.

Ionospheric storms may last from a few minutes to several hours; the intensity then diminishes, and the effects disappear in a few days. During the peak of the storm and for a period thereafter it may be necessary to use lower than normal frequencies, especially in high latitudes.

SPORADIC DISTURBANCE IN THE E LAYER.—Frequently, "clouds" of abnormal ionization occur at the approximate altitude of the E layer. The occurrence is spotty both in time and place. This results in excellent reception within the normal skip distance, and occasionally long distance communication may be obtained above 60 MHz. The frequency may have to be lowered to maintain communications over short skip distances.

SCATTERED IRREGULARITIES IN THE IONOSPHERE.—Scattered irregularities in ion density may cause scattered reflections and resultant signal fading. This is due to varying phase relations resulting from variation in signal path lengths. It is a situation that must be tolerated.

EFFECT OF METEORITE TRAILS.—Large numbers of meteorites enter the upper atmosphere during the course of a day. A portion of the energy released as these particles are slowed down is utilized in ionizing the atmosphere. The volume of the atmosphere ionized by one of these particles is very large, considering the size of the particle. It may be several feet in diameter and perhaps a mile or more in length. Even though recombination of the ions occurs very rapidly, nevertheless ionization often lasts long enough to cause radio stations to be heard that would not normally come through.

Research is currently being done in this field, and perhaps the effect of meteorite trails on propagation may, in time, be used to great advantage.

Regular Ionospheric Variations

ELEVEN-YEAR SUNSPOT CYCLE.—Periods of maximum sunspot activity occur 11 years apart. During these periods, the F1 and F2 layers, especially, increase in density and height. In general, higher operating frequencies are necessary for long distance communications.

SEASONAL VARIATIONS.—During the summer months the height of the F2 layer is increased, and during the winter months it is decreased. During the winter months the ionization density rises earlier in the day, and reaches a higher value than in the summer months; the predawn ion density reaches a lower value. The F1, E, and D layers reach lower maximum densities in winter.

Medium high frequencies are used for long distance, winter communication; the lower high frequencies are used for medium distance communication.

TWENTY-SEVEN-DAY SUNSPOT VARIATIONS.—These disturbances accompany sunspot activity that occurs every 27 days. This interval is the time required for the sun to complete one revolution about its axis. The effect on radio transmission is essentially the same as that of sudden ionospheric disturbances.

DIURNAL (DAILY) VARIATIONS.—During the daylight hours the density of the F layers increases; the thickness of these layers also increases during this time. During the course of the day, the F layer splits into the F1 and F2 layers. The ion density of the F1 layer varies with the vertical angle of the sun, and the ion density of the F2 layer increases to a peak somewhat later in the day.

The ion density of the E layer varies with the vertical angle of the sun, and the height remains approximately constant; the E layer is much weaker at night.

The D layer appears after dawn, and the ion density varies with the vertical angle of the sun; it disappears at night. The D layer is located between 40 and 50 miles above the earth's surface.

PROPAGATION

Frequency Bands

The frequencies with which the AT normally works range from about 15 Hz or less up to about 300 GHz (300,000,000,000 Hz) or higher. For convenience, these frequencies are divided into BANDS. Audiofrequencies extend from about 15 Hz to about 15,000 Hz, and embrace those frequencies that are audible to the normal human ear. These frequencies are not normally connected with radiation and antennas.

The classifications of the various bands in the RF spectrum are shown in table 6-1. The frequencies included in the UHF and the microwave ranges are usually considered as 225 MHz through 30 GHz, indicating that there are some areas of overlapping in this type breakdown. In order to prevent confusion and to further break these important bands into smaller divisions, the system of classification shown in table 6-2 has been adopted.

Figure 6-4 shows the frequency distribution in the RF spectrum. The figure also indicates the uses to which portions of the RF spectrum are put. For example, the radar bands extend from the VHF to the EHF band; the commercial television channels cover portions of the VHF and UHF bands; and communications make use of all of the bands except the EHF. Newer developments indicate that even the EHF band will be used in the near future. The approximate distances covered are also indicated, as well as the types of transmission lines commonly used and the types of interference commonly experienced.

Critical Frequency

The higher the frequency of transmission the lower must be the angle of radiation for effective transmission. This results from the fact that high frequency radiation passes through into space and is effectively lost when the angle of radiation is high. Low frequency radiation may be returned to earth even if it is radiated vertically upward. (As a matter of fact, the effective height of the ionosphere can be determined by directing low frequency pulses vertically upward toward the ionosphere and measuring the time lapse between the transmitted pulse and the echo. Knowing the velocity of radio waves, it is relatively easy to compute the effective distance.)

If the frequency is increased while the height measurements are made, it will be found that above a certain frequency (the CRITICAL FREQUENCY) echoes are not returned to earth. However, if the radiation angle is reduced sufficiently, echoes will be returned to earth at some distance from the antenna. The distance depends on the height and density of the ionosphere.

For the E layer, the critical frequency is from 1 to 4 MHz, depending on the ion density of the E layer. For the F2 layer (daytime), the critical frequency is approximately 2.5 MHz; and for the F layer (night), it is approximately 12.5 MHz.

Table 6-1.—Radiofrequency classifications.

Band	Frequency spectrum (KHz)	Wavelength in meters
VLF (Very Low)	10 - 30	30,000 - 10,000
LF (Low)	30 - 300	10,000 - 1,000
MF (Medium)	300 - 3,000	1,000 - 100
HF (High)	3,000 - 30,000	100 - 10
VHF (Very High)	30,000 - 300,000	10 - 1
UHF (Ultrahigh)	300,000 - 3,000,000	1 - 0.1
SHF (Superhigh)	3,000,000 - 30,000,000	0.1 - 0.01
EHF (Extremely High)	30,000,000 - 300,000,000	0.01 - 0.001

Maximum Usable Frequency

Because less energy is absorbed out of high frequency radiation during transmission, it is desirable to know the maximum usable frequency (MUF) that may be employed in transmission. Higher frequencies will pass through the ionosphere and will be lost to the communication circuit, and lower frequencies will be seriously attenuated in the ionosphere.

Data on the maximum usable frequency is collected by the National Bureau of Standards and is made available to the Navy in the publication, Basic Radio Proagation Predictions.

Lowest Useful Frequency

As the radiated frequency is reduced below the MUF, more and more energy is absorbed from the wave and is lost, as far as communication is concerned. This absorption occurs principally in the D and E layers, which are maximum during the daylight hours, especially for frequencies between 500 kHz and 2,000 kHz. At the lowest useful frequency (LUF) the signal strength reaching the receiver barely overrides the background noise. Frequencies below this cannot override the noise and therefore serve no useful purpose.

Optimum Working Frequency

Because both the height and the density of the various layers of the ionosphere may change from hour to hour, it is not possible to predict the exact MUF for each hour. Predictions are based on averages made over a long period of time. Therefore, it is necessary to choose an operating frequency that will not shift above the MUF when sudden changes in ionosphere occur. This frequency (15 percent below the MUF for F2 transmission) is called the optimum working frequency. When the lowest usable frequency is only slightly below the maximum usable frequency, the 15 percent figure may not apply.

ANTENNA ARRAYS

In order to increase the effectiveness of the antenna system, several elements are often combined to form an array.

Table 6-2.—Radar frequency band code letters.

Band P		Band L			Band S			Band X			Band K			Band Q			Band V		
Freq	λ	Sub	Freq	λ	Sub	Freq	λ	Sub	Freq	λ	Sub	Freq	λ	Sub	Freq	λ	Sub	Freq	λ
0.225 0.390	133.3 76.9	P	0.390 0.465	76.9 64.5	E	1.55 1.65	19.3 18.2	A	5.20 5.50	5.77 5.45	P	10.90 12.25	2.75 2.45	A	36.00 38.00	0.834 0.790	A	46.00 48.00	0.652 0.625
		C	0.465 0.510	64.5 58.8	F	1.65 1.85	18.2 16.2	Q	5.50 5.75	5.45 5.22	S	12.25 13.25	2.45 2.26	B	38.00 40.00	0.790 0.750	B	48.00 50.00	0.625 0.600
		L	0.510 0.725	58.8 41.4	T	1.85 2.00	16.2 15.0	Y	5.75 6.20	5.22 4.84	E	13.25 14.25	2.26 2.10	C	40.00 42.00	0.750 0.715	C	50.00 52.00	0.600 0.577
		Y	0.725 0.780	41.4 38.4	C	2.00 2.40	15.0 12.5	D	6.20 6.25	4.84 4.80	C	14.25 15.35	2.10 1.95	D	42.00 44.00	0.715 0.682	D	52.00 54.00	0.577 0.556
		T	0.780 0.900	38.4 33.3	Q	2.40 2.60	12.5 11.5	B	6.25 6.90	4.80 4.35	U	15.35 17.25	1.95 1.74	E	44.00 46.00	0.682 0.652	E	54.00 56.00	0.556 0.536
		S	0.900 0.950	33.3 31.6	Y	2.60 2.70	11.5 11.1	R	6.90 7.00	4.35 4.29	T	17.25 20.50	1.74 1.46						
		X	0.950 1.150	31.6 26.1	G	2.70 2.90	11.1 10.3	C	7.00 8.50	4.29 3.53	Q	20.50 24.50	1.46 1.22						
		K	1.150 1.350	26.1 22.2	S	2.90 3.10	10.3 9.68	L	8.50 9.00	3.53 3.33	R	24.50 26.50	1.22 1.13						
		F	1.350 1.450	22.2 20.7	A	3.10 3.40	9.68 8.83	S	9.00 9.60	3.33 3.13	M	26.50 28.50	1.13 1.05						
		Z	1.450 1.550	20.7 19.3	W	3.40 3.70	8.83 8.11	X	9.60 10.00	3.13 3.00	N	28.50 30.70	1.05 0.977						
					H	3.70 3.90	8.11 7.69	F	10.00 10.25	3.00 2.93	L	30.70 33.00	0.977 0.909						
					Z	3.90 4.20	7.69 7.15	K	10.25 10.90	2.93 2.75	A	33.00 36.00	0.909 0.834						
					D	4.20 5.20	7.15 5.77												

(Frequencies are shown in gigahertz, wavelengths in centimeters.)

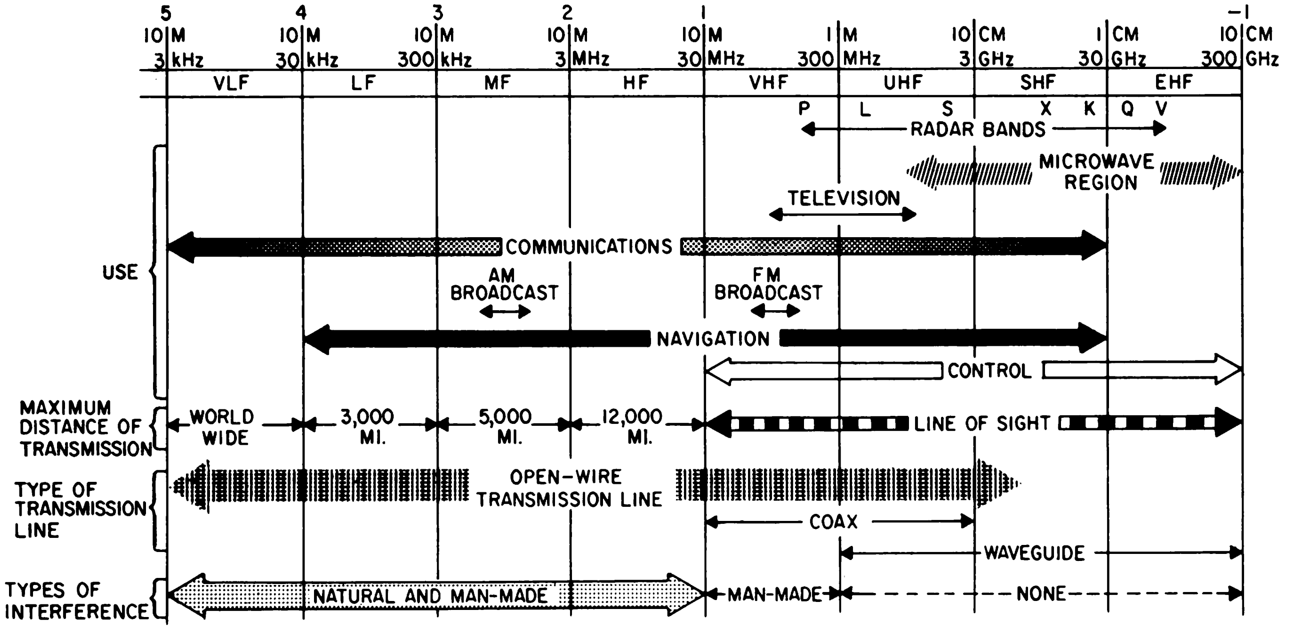

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Figure 6-4.—RF spectrum.

The simple half-wave dipole may be used in a variety of combinations to provide directive radiation patterns, with a signal increase in some directions, but reduction in others.

The antenna array to be used will be determined by the requirements of the equipment and the particular purpose of the transmission. UHF directive arrays containing several parasitic elements may be built into a very small space. Likewise, directive arrays with parabolic and horn type reflectors which would be too bulky for use at the lower frequencies become very practical at microwave frequencies because of their small physical size.

Directional arrays are more widely used with radar than the simpler vertical or horizontal antennas because of the increased gain due to the concentration of energy.

DRIVEN ARRAY

In the driven array, each of the individual conductors which comprise the array receives its energy from the transmitter. If a number of driven half-wave antenna elements are so positioned with respect to each other that energy arriving at a distant point from the individual elements will add in certain directions and cancel in other directions, then the antenna system is directional.

Signals arriving at any distant point in space from a number of different sources may contribute to or subtract from the net effect. By properly phasing the energy fed to the antenna elements and by properly locating the elements in space, the energy may be made to add in the desired direction and to be out of phase, or to oppose, in the undesired direction.

Driven arrays are usually made up of a number of half-wave dipoles so positioned in space and so phased that the desired directional pattern will be achieved. They may be classified into three basic types: the collinear array, the broadside array, and the end-fire array.

Collinear Array

A collinear array is formed when two half-wave elements are placed end to end and excited in phase. The resulting radiation is in a direction at right angles to any plane containing the antenna conductors. As with any of the other arrays, increasing the number of half-wave elements increases the directivity of the pattern. (See fig. 6-5.)

If radiation in only one direction is desired (and this is true in most radar installations), a metal screen is mounted behind the radiating antennas. The unit now is a combination driven and parasitic array. This is a common procedure in the use of driven arrays, producing better directivity (and more antenna gain) than is possible with the driven array alone.

Broadside Array

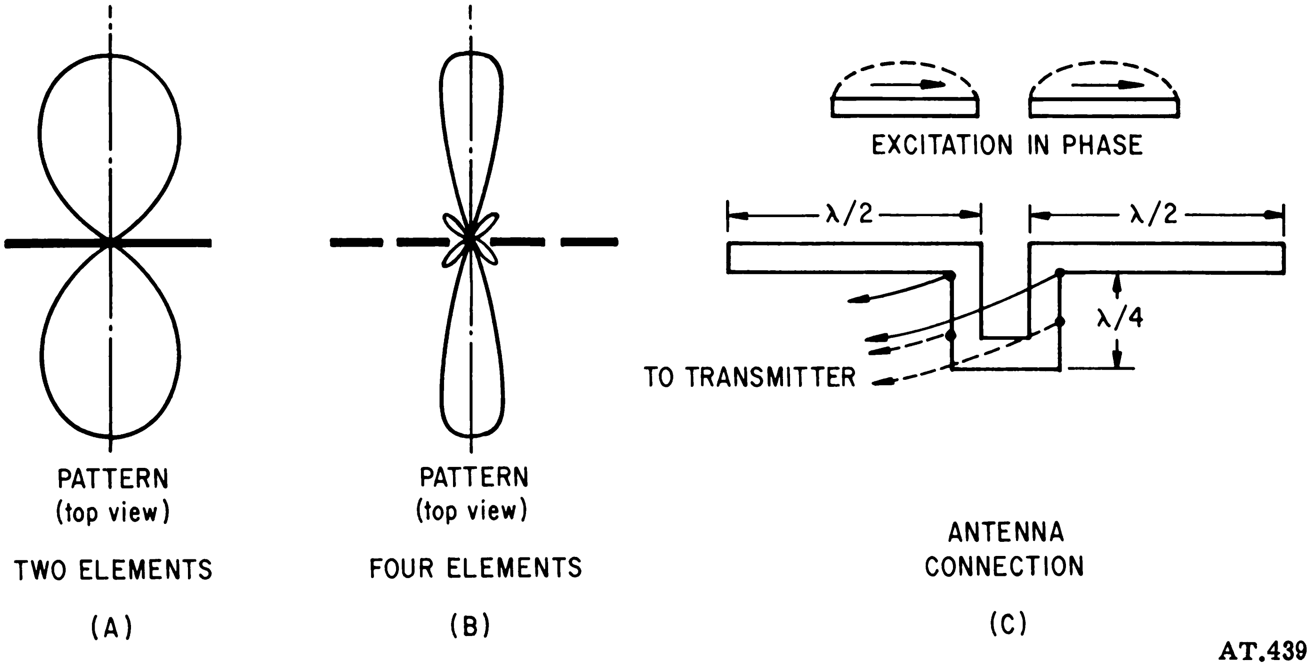
When two half-wave elements are placed one-half wavelength apart, parallel to each other and excited in phase, most of the radiation takes place in a direction perpendicular to a plane through the elements. The arrangement and radiation pattern of such an array, called a broadside array, are shown in figure 6-6.

The antenna elements are mounted one-half wavelength apart to simplify the problem of feeding the array with a single transmission line. In one-half wavelength, voltage and current polarities reverse. Therefore, by reversing the connections between the antenna elements (as shown in figure 6-6 (A)), all the elements in a vertical line may be fed in phase.

Because of the vertical mounting or stacking of the radiating elements, and because of the phasing of the currents and voltages, the vertical radiation from the array is small. Most of the energy is concentrated in the horizontal plane, and by using more elements in the array, this horizontal directivity can be further sharpened, as shown in 6-6(C). This increased directivity is shown by the dotted lines.

End-Fire Array

The end-fire array is so named because the principal radiation is off the ends of the array; that is, the radiation is maximum in the plane of the elements. This may be contrasted with the broadside array in which maximum radiation is perpendicular to the plane of the elements.



PATTERN (top view)
TWO ELEMENTS
(A)

PATTERN (top view)
FOUR ELEMENTS
(B)

ANTENNA CONNECTION
(C)

Figure 6-5.—Collinear arrays.

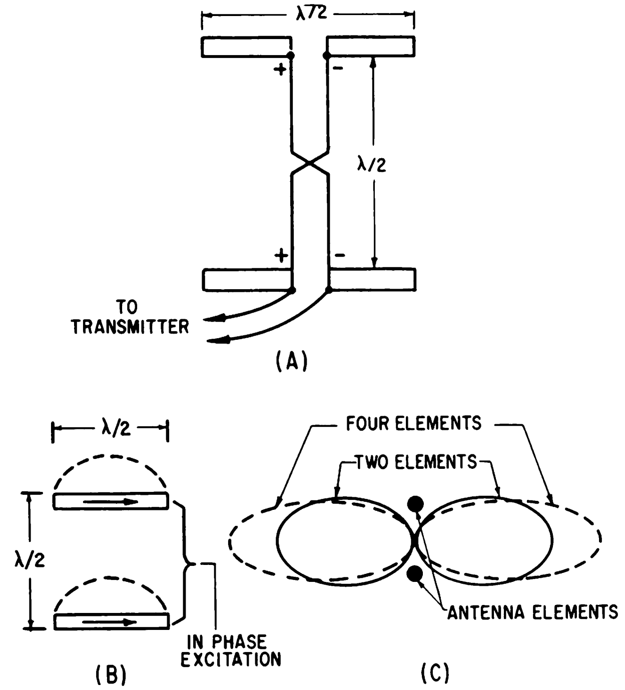


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Figure 6-6.—Broadside array.

A simple end-fire array employing two vertical half-wave antennas spaced λ/2 wavelength apart and fed 180° out of phase is shown in figure 6-7 (A). Because the two antennas are λ/2 wavelengths apart and fed 180° out of phase, radiated energy will reinforce along line 1-2 in the plane of the antennas. Likewise, radiated energy is canceled along line 3-4, broadside to the antennas.

If the spacing of the antennas is reduced to λ/4 wavelength, and the excitation of A lags that of B by 90°, a cardioid (heart-shaped) pattern is produced, as illustrated in figure 6-7 (B).

The cancellation of the radiated energy in the direction of B and the reinforcement in the direction of A may be explained as follows: By the time the radio wave leaving antenna B reaches antenna A, the wave leaving antenna A will have the same phase. Therefore, the two waves will add to produce maximum radiation in the direction shown (in the direction of A). However, by the time the radio wave leaving antenna A reaches antenna B, the wave leaving antenna B will be 180° out of phase, causing cancellation in the direction of B. Maximum radiation occurs in the direction of the antenna that lags.

Interconnection of Elements in Arrays

There are several ways to connect the elements in an antenna array to obtain the required phase of excitation. The most convenient method to change the phase from one element to another element when they are a half wave apart is with an RF line. In the broadside array shown in (A) of figure 6-6, one element is excited directly from the transmitter. This element is connected to the other element by a half wavelength of RF line. The phase of the voltage along the RF line is shifted 180° for each half wavelength. The leads to the second driven element are reversed. This causes a reversal of polarity similar to that resulting from another 180° phase shift. The second element is then excited in the same phase as the first.

In the end-fire array (fig. 6-7 (C)), the elements are also interconnected with RF lines. But instead of reversing the leads to the elements, they are connected directly to take advantage of the phase shift. With halfwave spacing, the interconnecting line will be one-half wave long and provide a 180° phase shift. If quarter-wave spacing is used, the interconnecting line will be one-quarter wave long; this arrangement produces a 90° shift.

The usual method for providing the correct phase in a collinear array is shown in (C) of figure 6-5. Since the current direction changes for each half wavelength of an antenna, it is not possible to connect the half-wave sections together directly. Instead, the half-wave section which carries the current in the wrong direction is folded to form a quarter-wave section of RF line. This brings together the ends of the sections in which current flows in the same direction. In other words, in terms of voltage it is necessary that the two antenna sections have voltages which are opposite in polarity at the open end. Further, note how the line to the transmitter is connected in the figure. The connection is made at a point of very high impedance. This requires the use of a resonant line. If a nonresonant line is to be used, it must be connected as shown by the dotted lines. In the diagram the connections near the closed end of the quarter-wave section are at a point of low impedance.

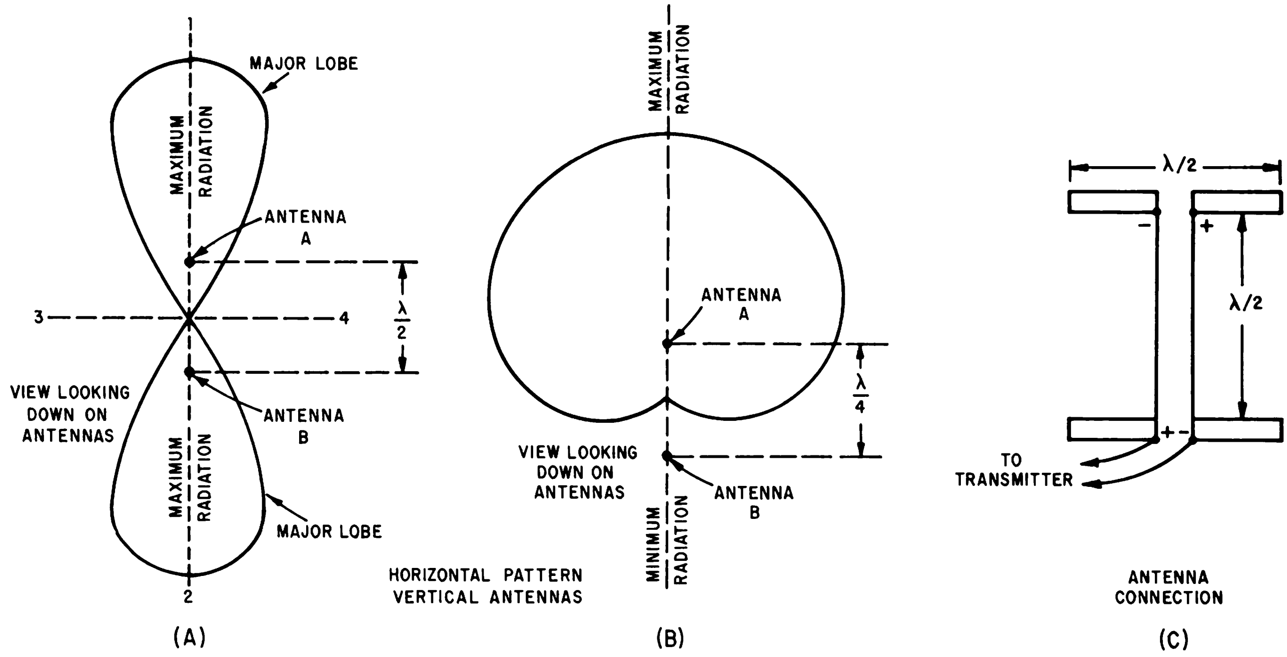


Figure 6-7.—End-fire array. (A) Half-wave spacing; (B) quarter-wave spacing; (C) antenna connection.

It is possible to connect any number of elements in this manner. Increasing the number of elements makes the array more directional.

PLANAR ARRAY

A planar array is a two-dimensional configuration of elements arranged to lie in a plane. (A linear array consists of elements arranged in a straight line in one dimension.) The two-dimensional planar array is probably the array of most interest in radar applications since it is fundamentally the most versatile of all radar antennas.

Radar beams can be rapidly scanned without any mechanical movement of antennas. Also, several independent beams can be generated simultaneously from the same antenna structure. When the array is mounted as a broadside array, the radiation pattern will be bidirectional and perpendicular to the plane of the array; with a reflector screen located a $\lambda/4$ behind the elements, the radiation pattern is unidirectional. When the array is mounted as an end-fire array, the radiation pattern will be bidirectional and parallel to the plane of the array.

A rectangular aperture can produce a fan-shaped beam. A square or a circular aperture produces a pencil beam. The array can be made to simultaneously generate many search and/or tracking beams with the same aperture (with the use of phase shifting devices).

PARASITIC ARRAY

A parasitic array is an antenna system which consists of two or more elements in which not all of the elements are driven. The other elements are excited by induction and radiation fields which are produced by the driven element. With parasitic arrays it is possible to obtain highly directional patterns. The action in a parasitic array is analogous to the action in a transformer in which the primary induces a current in the secondary and the current in the secondary produces a magnetic field which, in turn, induces current back into the primary. The phase relationship between elements in an array varies according to the spacing between elements. The elements are usually spaced an appreciable fraction of a wavelength apart.

Antenna with Reflector

In the two-element array shown in figure 6-8 (A), the DRIVEN ELEMENT is cut at the center for connecting a low impedance feed line. The length of the driven element is a half wavelength. This makes it self-resonant. A parasitic element (called the REFLECTOR) is located 15 percent of a wavelength in space from the driven element, and is about 5 percent longer than the driven element.

If the polar diagram is plotted for two elements spaced 0.15 wavelength apart and excited out of phase, the curve shown in (A) results. This shows that most of the radiation is on the side of the driven element which is away from the parasitic element, while very little occurs on the side of the reflector.

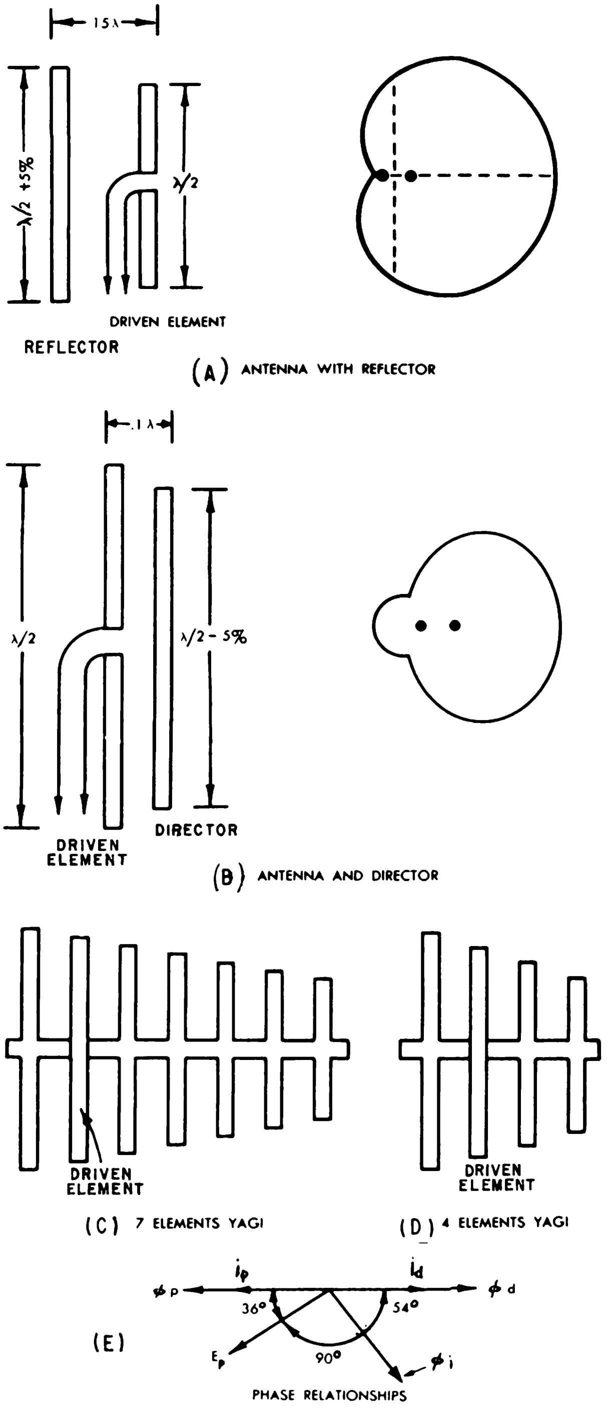
Another point is that the field passing from the reflector cuts the antenna (driven element) and induces a voltage in it. This voltage changes the input current. The input impedance, which is a function of this current, is about 50 ohms as compared to 73 ohms for the antenna alone.

Antenna with Director

A parasitic element becomes a director when it is made shorter than the antenna element. In a director most of the energy is sent in a direction from the antenna element to the parasitic element. To see what takes place, note the radiation pattern and the arrangement of the array in the diagram in (B) of figure 6-8. The director is usually about 5 percent shorter and about 0.1 wavelength from the antenna. Sometimes the impedance is reduced to 20 ohms at the driven element in this array.

Multielement Yagi

Notice the element array called a Yagi antenna in (C) of figure 6-8. In it the antenna or driven element is insulated, but the reflector, and all directors are welded to a piece of tubing which runs parallel to the direction of propagation. The beam width of this array is about 19°. The four-element Yagi shown in (D) is constructed similarly to the one in (C) and has a beam width of about 50°.



(A) ANTENNA WITH REFLECTOR

(B) ANTENNA AND DIRECTOR

(C) 7 ELEMENTS YAGI

(D) 4 ELEMENTS YAGI

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Figure 6-8.—Parasitic antennas and arrays.

Phase Relationships

Figure 6-8 (E) shows the phase relationship in the parasitic array vectorially. Vector i_d, which represents the current in the driven element, is in phase with the H-field. The part of the H-field that cuts the parasitic element lags the field which leaves the driven element by 0.15 of a cycle. (This is the time lapse during the travel between elements.) The lag is equivalent to 54°. The flux at the reflector is shown by vector ϕi. It lags i_d by 54°. The voltage induced by the field is 90° out of phase with the field. This voltage is represented by the vector E_p. If the parasitic element were resonant, the current in it would be in phase with E_p, but the reflector is longer than the resonant half wavelength. A long antenna is inductive and the current in this element will lag the voltage by 36° if it is approximately 5 percent longer. The radiated field will be in phase with this current. In summary, the field starting out from the parasitic element will be 180° out of phase with the field leaving the driven element.

Directivity

The conventional method for describing the directivity of an antenna array is in terms either of the ratio of the power in the best lobe to the power radiated by a simple half-wave antenna (antenna gain), or the ratio of the power in the direction of the best lobe to the power in the opposite direction (front to back ratio). The direction of the best lobe is usually called FORWARD direction, while that in the opposite is called the BACKWARD direction. In other words, this ratio is the power in the forward field to the power in the backward field. For example, the front to back ratio of the antenna array illustrated in (B) of figure 6-8 is about 5:1. In decibels, this represents approximately a 7-db gain. The ratio between forward power and power from a single half-wave antenna is about 4 db.

Comparison between the more directive types of arrays are made in terms of the beam angle. This angle is the angle between half-power points in the main lobe (radiation curve). In arrays the half-power points are the points where the electric field strength (volts per meter) is 0.707 times as great as that along the axis of the beam. Figure 6-9 shows the beam angle for a radiation pattern. In this illustration the angle between points A and B (angle ϕ) is the beam angle. At each of these points the signal strength is 70.7 percent of its value at point C. At A and B the power radiated is one-half the value as at C; thus these points are also known as half-power points.

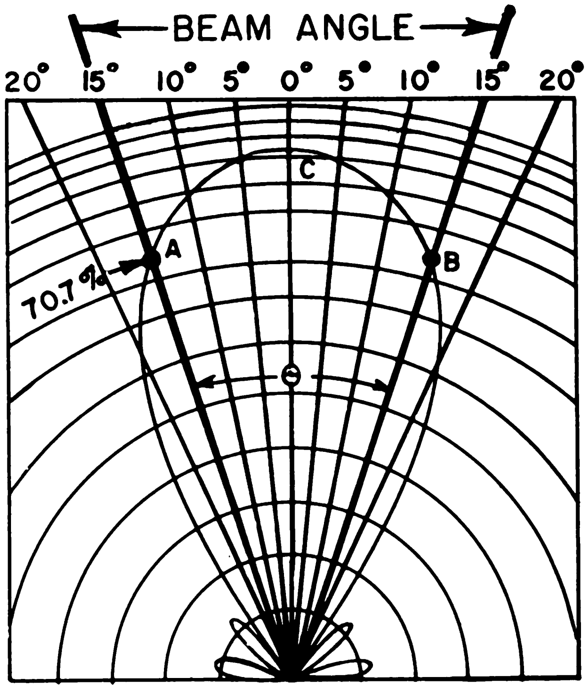

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Figure 6-9.—Beam angle.

Power Gain

Figure 6-10 shows the effect of the element spacing on the power gain of an array as compared to the field strength of a half-wave antenna alone. Curve A shows the power gain for director spacings in wavelengths between a half-wave director and the driven half-wave radiator. Curve B shows the power gain for half-wave reflector spacings between the reflector and the driven half-wave radiator.

The graph shows that when a single parasitic element is used, there is little difference in the gain of the array if the parasitic element employed is used either as a reflector or as a director. When the parasitic element is tuned to work as a reflector, the spacing which gives maximum gain is about 0.15 wavelength

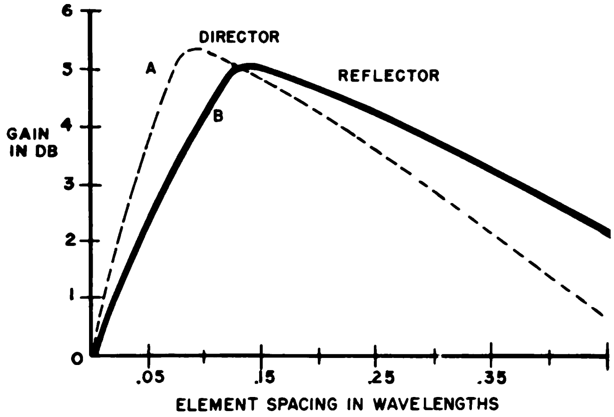

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Figure 6-10.—Relative power gain for parasitic elements.

and this maximum gain peak is fairly broad. The director will give slightly more gain than the reflector, but the difference between the two is less than 0.5 db. Consequently, on the basis of gain, there is little choice between the two types of operation. The broader curve of the reflector does offer a distinct advantage in that the spacing is less critical. Similarly, a smaller error in reflector spacing will reduce the gain of the array less than the same spacing error in a director type array. For this reason, when a single element is used, the array is usually a reflector type array.

Several parasitic elements can be used in conjunction with a driven antenna to increase further the directivity and power gain. The theoretical power gain of directional antenna arrays composed of an excited element and various numbers of parasitic elements is given in table 6-3.

Table 6-3.—Theoretical power gain.

Number of elements	Power gain
2	2.5 (4.0 db)
3	3.6 (5.6 db)
4	5.0 (7.0 db)
5	6.4 (8.1 db)

Impedance Considerations and Matching

In multielement arrays the input impedance drops as low as 15 ohms. In these arrays special matching devices are needed for matching this low impedance to the higher impedance of most RF lines.

One method for making the match is to use the delta matching system in which the end of the transmission line that is to be connected to the antenna is spread apart (fanned out) before being connected. The section of the line that is spread apart has a continuously increasing characteristic impedance. The impedance of a half-wave radiator increases from 73 ohms in the center to about 2,500 ohms at the ends. Thus, the impedance at any point is determined by the distance from the center. Two points can be found on the radiator where the impedance equals that of the fanned section of the transmission line. The connections are made at these points.

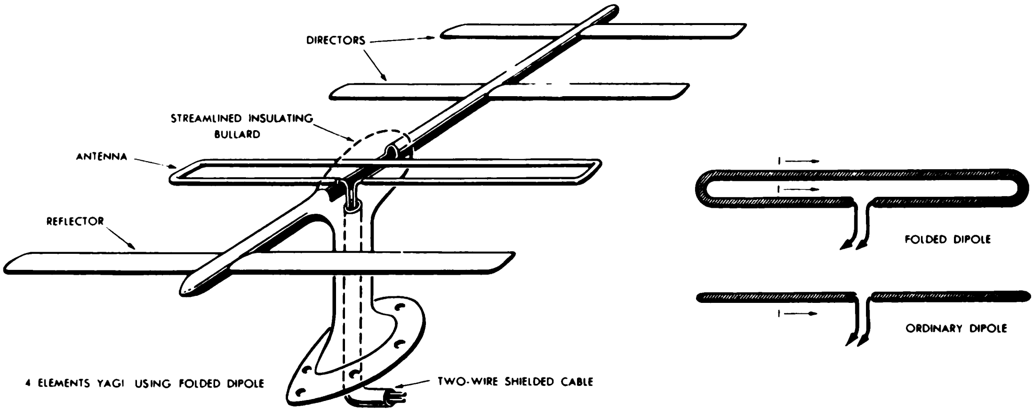
Another method, the one most often employed, uses the folded dipole as shown in figure 6-11.

A folded dipole is a full wavelength conductor which is folded to form a half-wave element. (A better description is that it consists of a pair of half-wave elements connected together at the ends.) In it the voltage at the ends of each element must be the same. In operation, the field from the driven element induces a current in the second element. This current is the same as the current in the driven element.

An ordinary dipole with a given current, I, produces a certain field intensity in space. Due to this field, there is also a certain power density per square meter in space. This power density is produced by the input power, P. The relationship between the input resistance, the current, and the input power is expressed by the equation,

$$R = \frac{P}{I^2}$$

With the folded dipole, the same current, I, exists at the input terminals; but this same current flows in both sections of the antenna, and consequently, the field strength in space is doubled. This causes the power density per square meter to increase to four times the



Folded Dipole

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Figure 6-11.—Folded dipole antenna array.

previous value when the current at the input remains unchanged. In turn the input power must be four times as great. In this case, to balance the equation, it is necessary to multiply R by 4 as follows:

$$\frac{4P}{I^2} = 4R$$

So long as each section of a dipole has the same diameter, the input resistance is four times that of the simple half-wave dipole. Increasing the diameter of one section makes the increase in impedance still greater. The input impedance to the driven element of a parasitic array drops to about a fourth of the value of the coaxial cable impedance, but the use of a folded dipole increases the impedance by about four times. In this way a good impedance match is achieved.

PARABOLIC REFLECTOR

When a multielement broadside array is excited, the E-field which exists in front of the antenna will be a single plane, as shown in (A) of figure 6-12, rather than in an arc as is the case in a single half-wave element. The larger the dimensions of this plane in terms of wavelengths, the greater is the directivity of the antenna system, and the narrower the radiated beam.

Although a multielement broadside array gives good results, it is quite complicated in structure. In it every element must be driven and all spacings and dimensions must be quite exact. A much simpler device for producing an electric field in a single plane is the parabolic reflector. As shown in (B), the parabola has its focal point at F. If a single antenna is placed at F and caused to radiate a field, the electric field will leave the antenna in all directions at the same rate in the form of an arc as indicated at point A. As each part of the wavefront reaches the reflecting surface, it is shifted in polarity and sent outward at an angle of reflection that is equal to the angle of incidence. All parts of the field will arrive at line BB' at the same time after reflection because all paths from F, to the reflector, to line BB' are equal in length. Thus, with only one antenna and a specially shaped reflector, it is possible to produce a large electric field in a single plane. Or, looking at it another way, all parts of the field travel in parallel paths after reflection from the parabola in such a way that the rays are focused like the headlight beam from an automobile.

Like the broadside array, high directivity is not obtained until the diameter of the parabolic reflector is made many wavelengths long. This prohibits the use of the parabolic reflector at low frequencies, but for 3-centimeter and 10-centimeter radar equipment these reflectors are very practical.

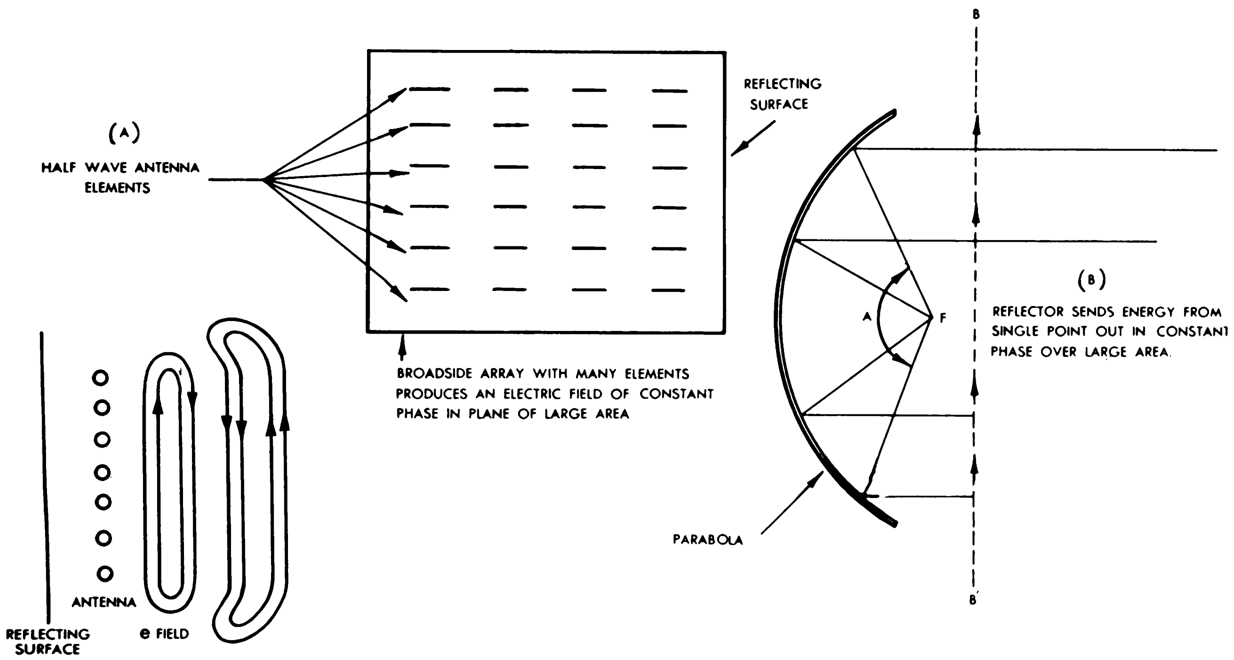
(A)
HALF WAVE ANTENNA ELEMENTS
REFLECTING SURFACE
BROADSIDE ARRAY WITH MANY ELEMENTS PRODUCES AN ELECTRIC FIELD OF CONSTANT PHASE IN PLANE OF LARGE AREA
ANTENNA
REFLECTING SURFACE
e FIELD
B
A
F
(B)
REFLECTOR SENDS ENERGY FROM SINGLE POINT OUT IN CONSTANT PHASE OVER LARGE AREA.
PARABOLA
B'

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Figure 6-12.—Directional radiation by means of reflectors.

Feed Systems

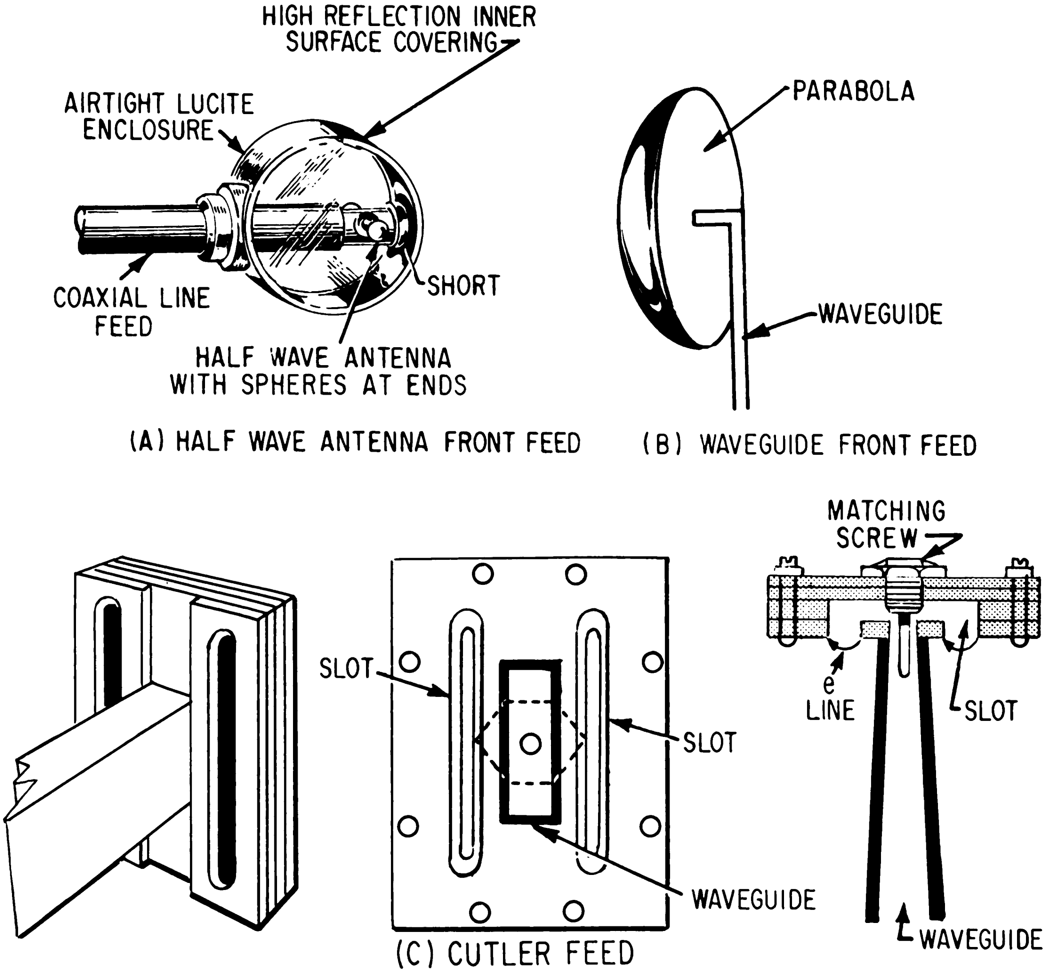
In figure 6-13 (A), showing the exciting antenna for a parabolic reflector, the half-wave dipole is mounted a quarter wave back from the short on the coaxial line. To sharpen the focal point, the antenna is made physically less than a half wave long. However, the balls at the end make it electrically a half wave long. This broadens the band of frequencies it will handle. The airtight cylinder in which the antenna is enclosed permits the coaxial line to be pressurized. The inner surface of half the cylinder on the side away from the parabolic reflector is coated with a reflecting foil. This reflecting surface directs energy from that side of the antenna into the large reflector. Without this reflector, the antenna radiation would be nondirectional.

The natural directivity of a dipole causes the pattern from a parabolic reflector to be somewhat sharper in the plane containing the dipole than in the other plane. For this reason, the dipole is erected horizontally for maximum azimuth accuracy in radar systems. If vertical accuracy is of primary importance, the dipole is mounted vertically.

Other methods of preventing the direct forward radiation use a parasitic reflector with the half-way dipole, and a disk which is placed in front of the dipole.

A waveguide can be used to bring energy to the parabolic reflector by placing the mouth of the guide at the focal point of the parabola and positioning it so that the energy strikes the parabolic reflector. A typical application is shown in (B). The most easily constructed waveguide feed is simply an open-ended waveguide. The energy from the transmitter comes streaming down the guide, passes out through the open end and, if this is facing the parabolic reflector, strikes the reflecting surface. Sometimes the end of the waveguide is tapered, so that the energy may be distributed horizontally or vertically to produce a desired pattern after it is reflected by the paraboloid. By modifying the shape of the feeding waveguide, this energy can be concentrated in one direction and, in conjunction with the parabolic reflector, achieve a desired radiation pattern.

One difficulty that is encountered when using waveguides to feed energy to parabolic reflectors is the fact that the guide, passing in


HIGH REFLECTION INNER SURFACE COVERING
AIRTIGHT LUCITE ENCLOSURE
COAXIAL LINE FEED
SHORT
HALF WAVE ANTENNA WITH SPHERES AT ENDS
PARABOLA
WAVEGUIDE
MATCHING SCREW
SLOT
SLOT
WAVEGUIDE
e LINE
SLOT
WAVEGUIDE

(A) HALF WAVE ANTENNA FRONT FEED

(B) WAVEGUIDE FRONT FEED

(C) CUTLER FEED

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Figure 6-13.—Feed systems for parabolic reflectors.

front of the reflector, tends to block part of the energy reflected by the paraboloid. To avoid this difficulty, several rear feeds have been developed. In this form of feed, the waveguide passes through the vertex of the paraboloid and extends to the focus, at which point the energy is redirected back to the reflecting surface of the paraboloid and then radiated in the forward direction. The most widely used and most successful of these "rear-feed" arrangements is the Cutler feed shown in (C).

The waveguide is terminated in front of the reflector in a Cutler feed radiator, which in reality is a cavity at the end of the waveguide. It can be considered as two small waveguides formed as a result of dividing the main wave into two halves, and bending each half through 180°. The fields emerge from openings or slots that are a half wave apart as shown in the drawing. The waveguide is tapered in the noncritical dimension to fit between the slots. The cavity impedance is matched to the waveguide by the matching screw. This adjustment is made at the factory and soldered in position. The radiated field is horizontally polarized. The design of the cavity is such that the energy striking the reflector decreases sinusoidally from the center toward each edge.

Variation of Parabolic Reflectors

It is possible to concentrate energy in one plane only, by using a section of a parabolic reflector. Thus, with the parabolic cylinder shown in figure 6-14 (A), directivity is obtained in the plane perpendicular to the length of the cylinder. In the figure, this would mean sharp vertical directivity. Parabolic cylinders do not have single focal points as paraboloids do, but rather a focal line. Small dipple antennas are mounted along this line, the useful energy radiating back toward the reflector and then forward by reflection from the surface. The horizontal directivity of this reflector is determined by the number of half-wave dipoles used and the phasing of the currents and voltages fed by a transmission line to the dipoles. The greatest directivity, however, is obtained in the vertical plane and this is determined by the parabolic surface.

Another section of a paraboloid which is of interest is the truncated paraboloid shown in (B) of figure 6-14. This is energized by either a single dipole or a waveguide placed at the focal point. Directivity in the horizontal plane is essentially the same as that obtained from a paraboloid; directivity in the vertical plane is not quite as good. This type of antenna would be suitable for ground to air or ground to ground surface search.

When a waveguide is used in the RF system, it is possible to send the energy into the parabolic reflector with a horn radiator. In this case an orangepeel reflector (fig. 6-14 (C)), or section of a complete circular paraboloid may be used as the reflector. The feed is by a waveguide and a horn type radiator. The horn type radiator and orangepeel parabola are constructed so that almost all of the energy that the horn radiates is intercepted and reflected by the reflector. This arrangement is highly directive in the vertical plane and is used principally to determine the altitude of aircraft.

Cosecant-Squared Reflectors

Because of the variety of the applications of radar, widely different requirements must be met by different antennas. Antennas designed to produce special polarization effects or pattern shapes may differ greatly from those already described. In airborne radar sets that are designed for use in scanning a large area, a special beam shape is required.

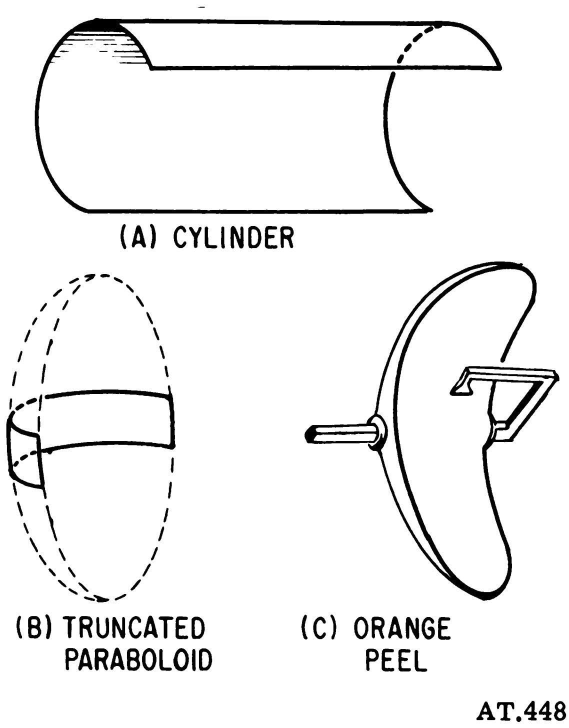

Figure 6-14.—Variations of the parabolic reflector.

This beam should be narrow in the horizontal plane, but broad in the vertical plane. In addition, the particular section of the area being scanned must not be uniformly illuminated by the radar beam. Instead, the objects near the aircraft should be illuminated by less power than those farther away in the same sector, because echo signals from nearby objects will be strong due to their closeness to the plane. On the other hand, a greater amount of power should fall on more distant objects in this sector, since they would normally produce the weakest echoes. Thus, the radiated field of the beam should increase in intensity at the greater distances. Figure 6-15 (A) shows some trigonometrical relationships of this situation.

If the aircraft is at point A in figure 6-15 (A), and the target is at point B, then the slant range (straight-line distance from A to B) can be represented in terms of the aircraft altitude

(h) and the angle of depression (θ) of the target as seen from the aircraft:

$$\frac{h}{r} = \sin\theta;\ r = \frac{h}{\sin\theta};\ r = h \csc\theta$$

Thus the slant range is proportional to the cosecant of θ.

An antenna has been designed so that the field intensity pattern is also proportional to cosecant θ; this antenna lays down a uniform electric field which causes the echo response of a nearby target to be approximately equal to that of a distant target having the same radar cross section (reflectivity). The equality of response is based on the concept of power density; research has shown that power density is proportional to the square of field intensity. This particular antenna, therefore, produces an electrical field whose power density is proportional to the square of cosecant θ.

Recalling from a review of Chapter 29 of Basic Electronics, NavPers 10087-C, Vol., 1a that RF signal strength is inversely proportional to the square of the distance from the source, note that a balance of signal loss against signal gain is utilized in this antenna. As the slant range r (fig. 6-15 (A)) increases, θ decreases and

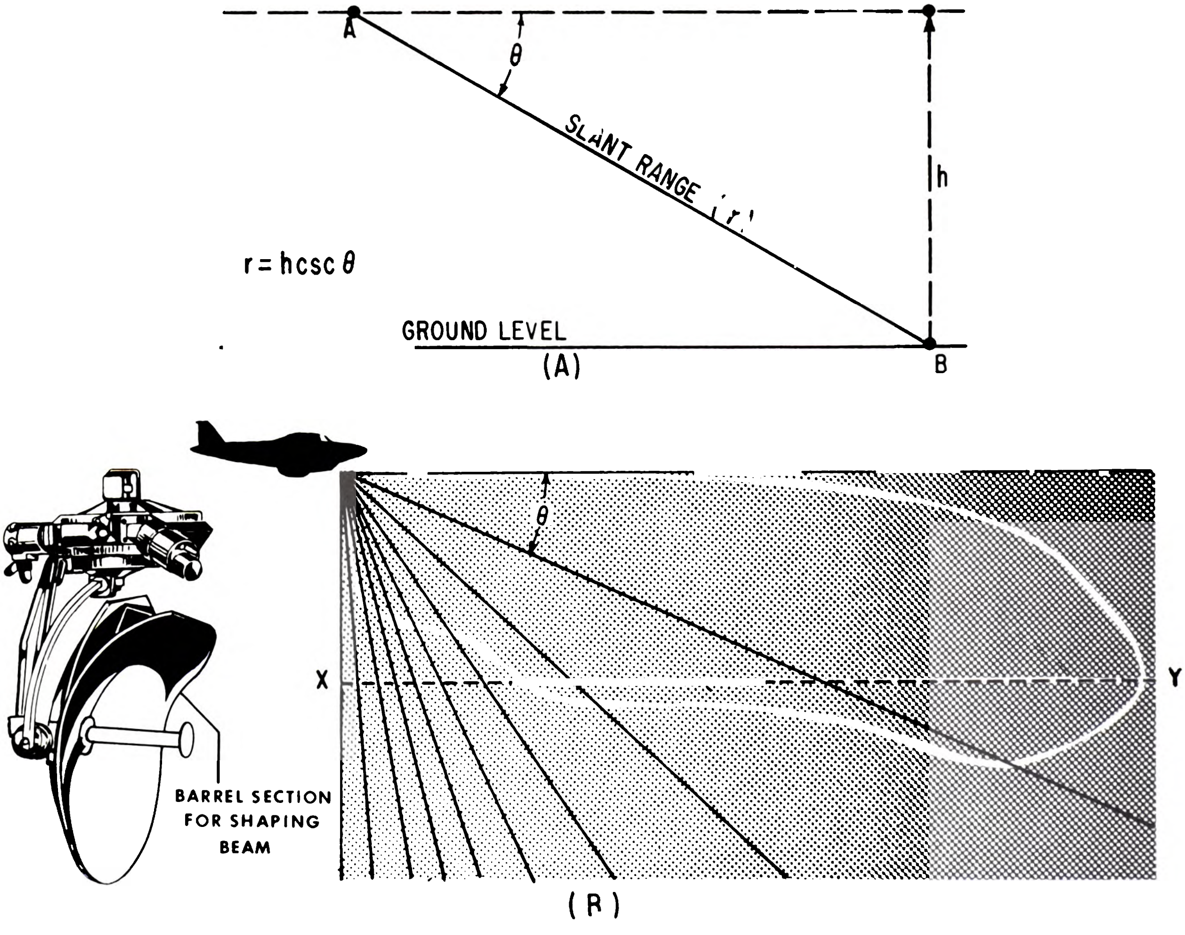

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Figure 6-15.—Cosecant-squared antenna and pattern.

csc θ increases. The signal strength (power density) is inversely proportional to the square of h csc θ because the wave is RF energy; at the same time, the signal strength is directly proportional to the square of csc θ because of the antenna design. (Assume that h is constant.) The result is a net change of zero (theoretically) in the signal strength up to the maximum range of the transmitter. The antenna design which produces this result is called the cosecant-squared antenna.

Figure 6-15 (B) shows the special paraboloid reflector, in which the top portion is bent forward to produce the cosecant-squared pattern. Also shown is the pattern itself. Notice that this antenna produces a field of constant signal strength (bounded by the white line) at ground level (line XY) over a broad range of values of θ.

This same type of antenna is also used (in an inverted position) on the land based and shipboard systems for obtaining equal indications from aircraft at equal altitudes but different ranges.

Another type of reflector is shown in figure 6-16. This reflector differs from the one just discussed in that it is capable of producing either a pencil type (narrow beam both vertically and horizontally) or a cosecant-squared pattern. Mounted on the reflector is a rod grating, roughly shaped in the form of a barrel stave, which is polarized and acts as a spoiler to deform the pencil beam pattern into an equal energy return (cosecant-squared) pattern. The choice of pattern desired may be obtained by rotating the entire reflector and grating 90° by means of a motor and gear train. In the position where the spoiler is nonreflective, a pencil beam pattern is produced. In the position where the spoiler is reflective, a narrow, blade-like pattern having equal energy return results.

Some reflectors of this type are equipped with a solid spoiler that is hinged to the upper part of the paraboloid. The desired pattern may be obtained by causing this spoiler to tilt out of the reflector to a position where the cosecant-squared pattern is produced. In the retracted position the spoiler is flush with the surface of the paraboloid and a pencil beam is produced.

TYPICAL AIRBORNE ANTENNAS

Until the past few years, the antennas used in airborne electronics were fairly standard. For a transmitter operating within a given frequency band, the same antenna was used as a standard installation item in all types of aircraft. With the modern concept of the weapons system, however, the electronic equipments and their antennas are designed along with the individual weapons system. This eliminates the interchangeability of antennas from one system to another. However, since the antenna is designed for a single specific application, it has decreased considerably in importance as a major source of trouble.

Although the antennas used with specific equipments in specific weapons systems are somewhat different from one another, they have certain basic similarities. There are general classes of antennas used, each for its own specific purpose. The various antenna components of the electronic packages are merely modifications of these basic types. The remainder of this chapter is devoted to a discussion of these types; some specific examples are mentioned, along with some of the new developments in antenna design.

GROUND-PLANE ANTENNAS

A vertical quarter-wave antenna several wavelengths above ground produces a high angle of radiation which is very undesirable at the VHF and UHF frequencies. An effective means of obtaining a low angle of radiation from this type antenna is to work it against a simulated ground (called a GROUND PLANE). This simulated ground may be made from a large sheet of metal, or from several wires or rods protruding from the base of the radiating element of the antenna. In another type, the outer conductor of a coaxial antenna may be flared out. An antenna so constructed is called a ground-plane antenna. The most noticeable difference between the ground-plane antenna and the reflector type antenna is the relative positions of the elements. In the reflector type antenna, the reflector element is mounted parallel with the driven element; while in the ground-plane antenna the ground plane is mounted perpendicular to it.

Several types of ground-plane antennas are shown in figure 6-17. The radius of the ground sheet or the length of the rods used should be one-quarter wavelength or longer. The function of a ground plane corresponds to that of a

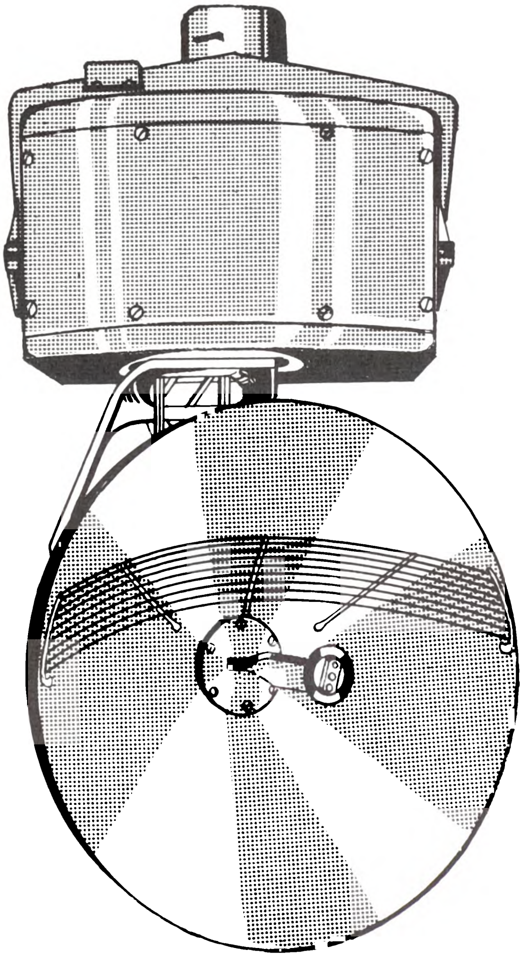

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Figure 6-16.—Parabolic antenna with spoiler.

counterpoise used with low frequency vertical antennas.

This type antenna is frequently used with VHF and UHF communications equipment in aircraft. The skin of the aircraft serves as the ground plane. When this type antenna is used with a ground installation, it is necessary to employ a ground plane as illustrated. Without the use of the ground plane, it is impossible to obtain proper loading and efficient radiation.

Since there are no ordinary transmission lines having a characteristic impedance low enough to permit a direct connection to the 20- to 36-ohm impedance of the ground-plane antenna, a quarter-wave matching section may be used to obtain an acceptable match.

If it is desired to avoid the use of a matching section with its accompanying power losses and bandwidth limitations, the radials can be arranged to slope downward in the manner of an inverted cone as shown in (C). The impedance increases as the angle between the radials and the horizontal plane increases. This method can be used to secure a suitable match to a 52-ohm transmission line. It is possible to use the rods or cables in the multiple capacity of a ground plane and as guy wires for mechanical support, while at the same time changing the impedance to obtain a proper match.

The impedance can be increased further to match a 72-ohm line by bending the radials down parallel to the transmission line, or by supporting the shaft as shown in (D).

SLEEVE ANTENNAS

The sleeve antenna is basically a vertical omnidirectional antenna developed from the ground-plane antenna by folding the ground plane back over the radiator (to form a sleeve) before flaring it out. This helps to minimize radiation from the feeder line. One type coaxial radiator is one-half wavelength long, with the top half a thin whip or rod, and the bottom half a comparatively large hollow metal tube or cylinder. The coaxial feed line is run up through the sleeve radiator or cylinder, as shown in (A) of figure 6-18. The center conductor of the coaxial line connects to the whip radiator, and the outer conductor connects to the sleeve radiator. Since there is no RF field within the sleeve, interaction between the radiator and the coaxial line is minimized.

The section of transmission line within the sleeve acts in conjunction with the sleeve to form a short circuited concentric line which has an extremely high impedance across the open end. This high-Q parallel resonant circuit minimizes coupling between the sleeve radiator and the transmission line or hollow supporting mast. Although the sleeve effectively decouples the section of line within it from the sleeve radiator itself, as well as from the upper radiator, there will still be some coupling between radiators and the section

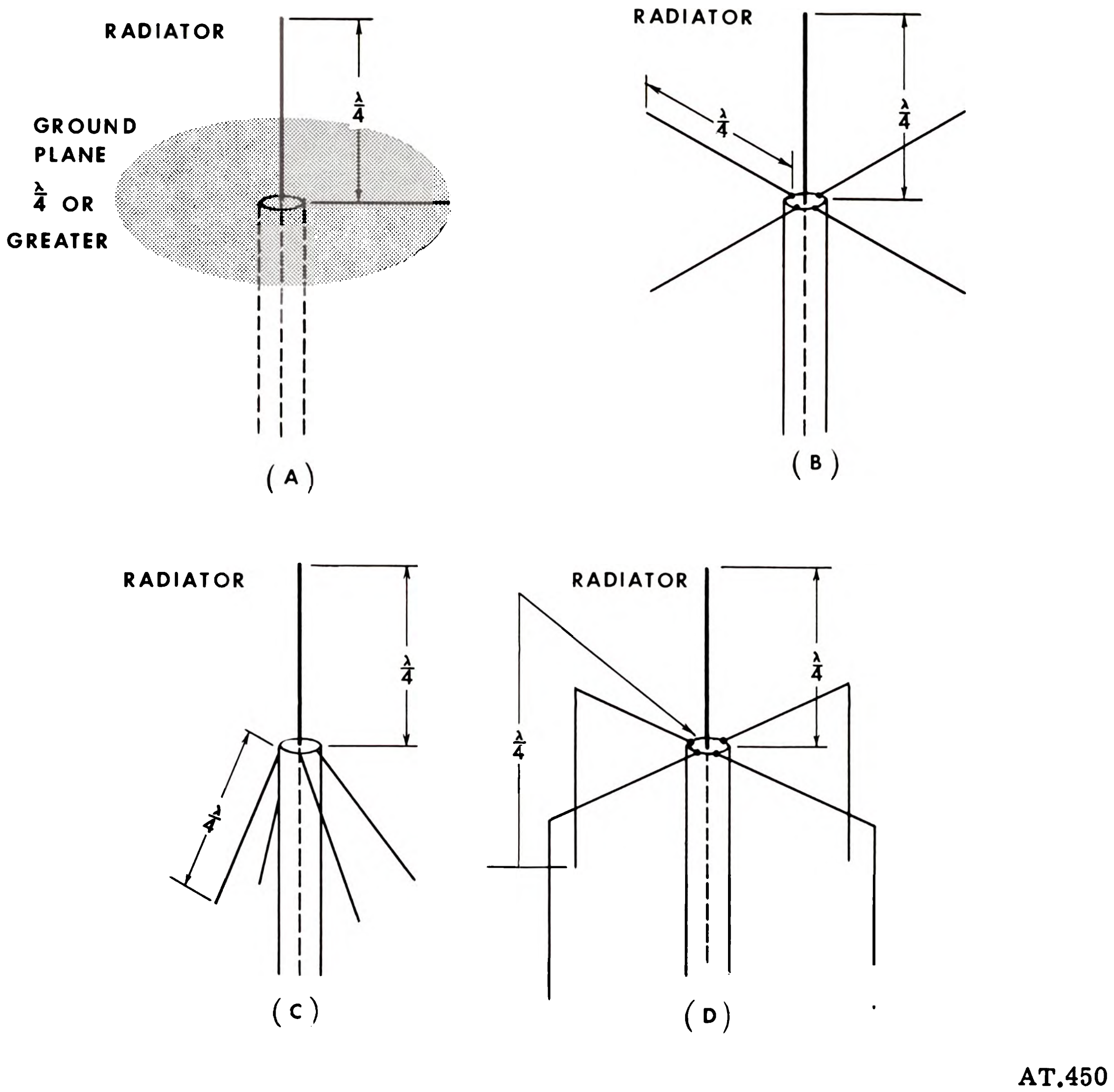

Figure 6-17.—Ground-plane antennas.

of transmission line or mast immediately below the sleeve. This coupling causes some radiation from the vertical portions of the line and/or mast, and as a result, some power is wasted in high angle radiation.

Radiation can be eliminated from the feeder and mast by placing a quarter-wave detuning sleeve below the sleeve radiator as shown in (B). The detuning sleeve is mounted with its open end facing upward, one-quarter wavelength below the bottom of the sleeve radiator. Its closed end is connected to the mast, or to the outer conductor of the coaxial feed line.

Inasmuch as the coaxial antenna is effectively a vertical, center fed, half-wave radiator, its center impedance is approximately 70 ohms. A 70-ohm feed line provides the most efficient match, but lines up to 120 ohms can be used without serious mismatch. It is possible to maintain a uniform impedance over a larger frequency band by increasing the diameter of the dipole, or by using a dipole constructed in the shape of a cone or cylinder.

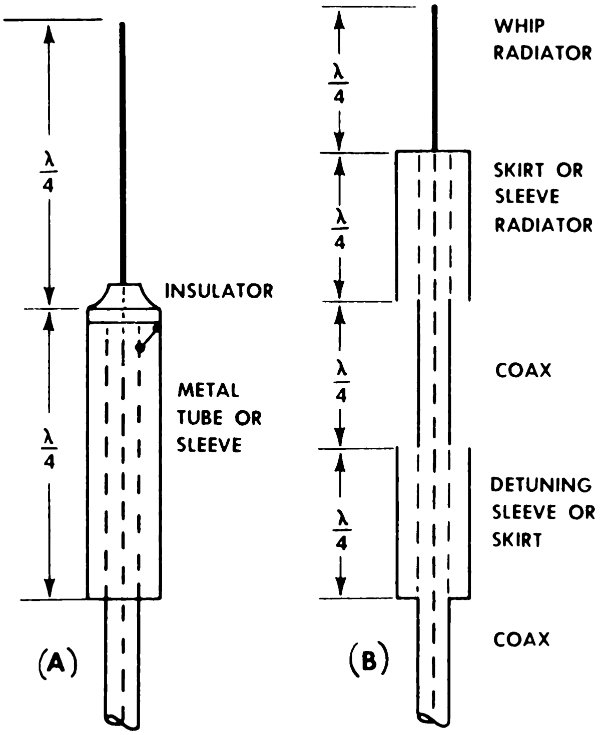

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Figure 6-18.—Sleeve antennas.

CORNER REFLECTOR

When a unidirectional radiation pattern is desired, such a characteristic can be obtained by the use of a corner reflector. A corner reflector antenna is a half-wave radiator with a reflector consisting of two plane metal surfaces meeting at an angle immediately behind the radiator. In other words, the radiator is set in the plane of a line bisecting the corner angle formed by the reflector sheets. The construction of a corner reflector is shown in figure 6-19 (A).

Corner reflector antennas are mounted with the radiator and the reflector horizontal when horizontal polarization is desired. In such cases, the radiation pattern is very narrow in the vertical plane, with the maximum signal being radiated in line with the bisector of the corner angle. The directivity in the horizontal plane is approximately the same as for any half-wave radiator having a single-rod type reflector behind it. If the antenna is mounted with the radiator and corner reflector

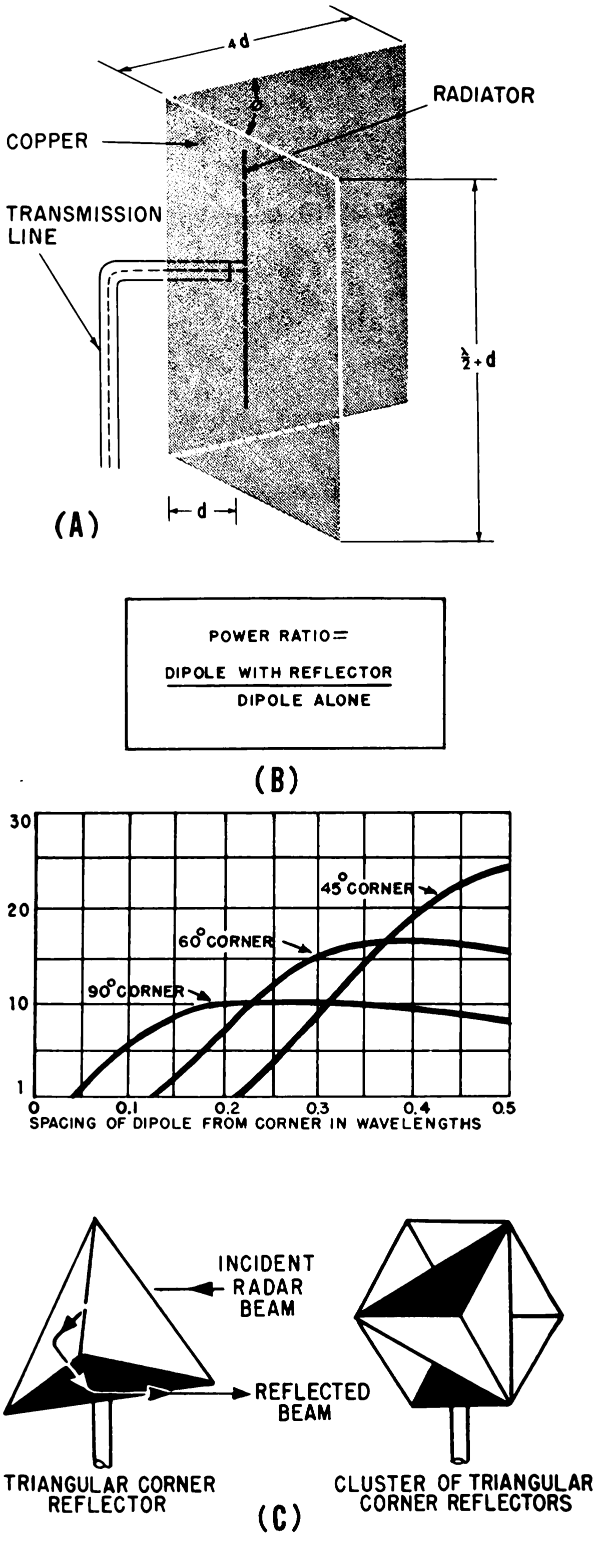

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Figure 6-19.—Corner reflector antenna.

vertical (as shown), maximum radiation is produced in a very narrow horizontal beam. Radiation in a vertical plane will be the same as for a similar radiator with a single-rod type reflector behind it.

At frequencies in the VHF and UHF bands, the corner reflector is often made from solid metal sheets. At lower frequencies, such sheets are massive and are easily damaged by high winds. Therefore, screen wire or metal rods located in the plane of the reflector sheets and running parallel to the radiator are used instead. The spacing between the rods must not be more than 0.06 wavelength at the operating frequency.

The gain and the radiation resistance of a corner-reflector antenna are both affected by the reflector corner angle Φ and the spacing, d, between the radiator and the corner as shown in (A), as well as the construction of the antenna and reflector. The gain (expressed as a power ratio between the dipole with a reflector and the dipole alone) for several corner-reflector antennas is shown in the graph in (B). Here the gain is shown for various spacings between the dipole and the corner reflector, and for an angle Φ of 90°, 60°, and 45°.

Sometimes the corner reflector is used as a PASSIVE RADIATOR. Under these conditions, the reflector is not excited by a dipole that is mounted with the reflector. Instead, the reflector is acted on by a distant transmitting antenna. Here, the purpose of the corner reflector is to return the greatest amount of energy possible back in the direction from which it originally came.

The most important use of the corner reflector as a passive radiator is in radar applications. Here, it is sometimes necessary to make good radar targets from objects which do not ordinarily reflect back enough of the transmitted radar beam to disclose their presence. For example, it is normally very difficult for a search radar to locate a rubber liferaft, particularly in a rough sea. If a corner reflector is installed on the raft, then it becomes possible for an aircraft radar to detect the raft over a distance of many miles. Corner reflectors are also used to mark the edges of landing fields or a particular runway so as to provide a well marked point for the aircraft or ground radar equipment. Corner reflectors are frequently installed on important buoys or strategic points of land which would otherwise not be good radar targets.

The appearance of a corner reflector used for marking radar targets is shown in figure 6-19 (C). Three mutually perpendicular metal surfaces similar to the arrangement of the floor and two sidewalls at a room corner are used. It should be noted that in the passive corner reflector the corner angle Φ is always 90°. If a radar beam is directed into the reflector, reflections may occur from all three surfaces, from two surfaces, or from one surface, depending on the angle of arrival of the beam. In any case, the reflections cause the radar beam to be returned in the direction from which it came. Under these conditions, the radar antenna picks up the reflected energy and detection occurs.

A single corner is effective only for energy that arrives from directions covering one octant of a sphere centered at the reflector. If it is desired to have coverage in all directions (such as would be the case for liferaft detection), then a cluster of eight such corner reflectors is used.

The size of such reflectors is not critical so long as the length of a short side is many wavelengths long at the frequency of the detecting radar. The corner reflector cluster which is included as part of the emergency rescue equipment on liferafts is a collapsible structure made of screen and measuring 2 feet on a short side. The reflector is mounted about 4 feet above the raft.

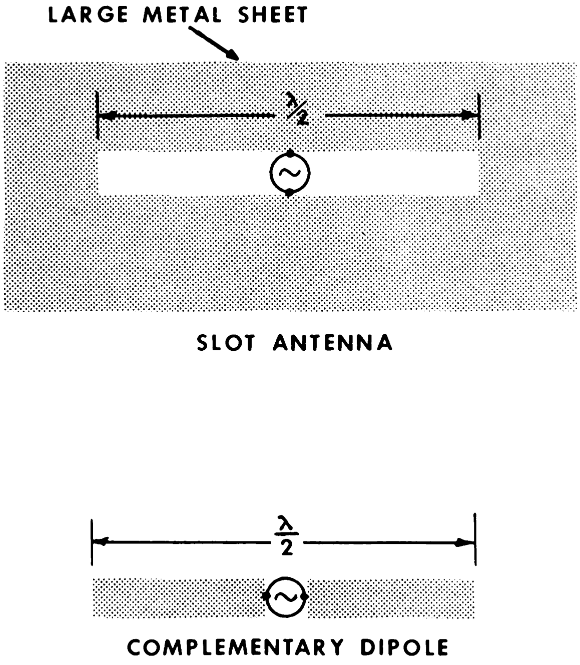
SLOT ANTENNAS

Slot antennas are adaptable for the VHF and UHF ranges. Their most important practical advantage is that the feed section which energizes the slot may be placed below the large metal surface in which the slot is cut. Thus, nothing need protrude from the surface. In addition, the slot itself may be covered by a section of insulating material so that the opening is closed. As a result, no air resistance occurs. This is particularly important in the case of high speed aircraft where the vibration problems and drag that would be introduced by conventional antennas cannot be tolerated.

When a slot antenna is installed on an aircraft, particular attention should be paid to the slot location with respect to large protuberances. Wings, fuselage, or engine will act to cut off a large portion of the energy radiated from a slot if these objects are located between the slot and the receiving location. Optimum locations for slot antennas on aircraft include the leading edge of the wing and the side of the nose.

Basic Slot Antenna and Its Complementary Dipole

The slot antenna consists of a radiator formed by cutting a narrow slot in a large metal surface. Such an antenna is shown in figure 6-20. The slot length is a half-wave while the width is a small fraction of a wavelength. Such an antenna is frequently compared to a conventional half-wave dipole consisting of two flat metal strips whose sizes are such that they would just fit into the slot cut out of the large metal sheet. This type is called the COMPLEMENTARY DIPOLE. This comparison is made since the radiation pattern produced by the slot antenna when cut into an infinitely large metal sheet and that of the complementary dipole antenna are the same.



AT.453
Figure 6-20.—Slot and complementary dipole antennas.

It is of interest to note several important differences between the slot antenna and its complementary antenna. First, the electric and magnetic fields are interchanged. In the case of the dipole antenna shown, the electric lines are horizontal while the magnetic lines form loops in the vertical plane. With the slot antenna, the magnetic lines are horizontal and the electric lines are vertical. The electric lines are built up across the narrow dimension of the slot. As a result, the polarization of the radiation produced by a horizontal slot is vertical. If a vertical slot is used, the polarization is horizontal.

A second difference between the slot antenna and its complemtary dipole is that the direction of the lines of electric and magnetic force reverse abruptly from one side of the metal sheet to the other. In the case of the dipole, the electric lines have the same general direction while the magnetic lines form continuous closed loops.

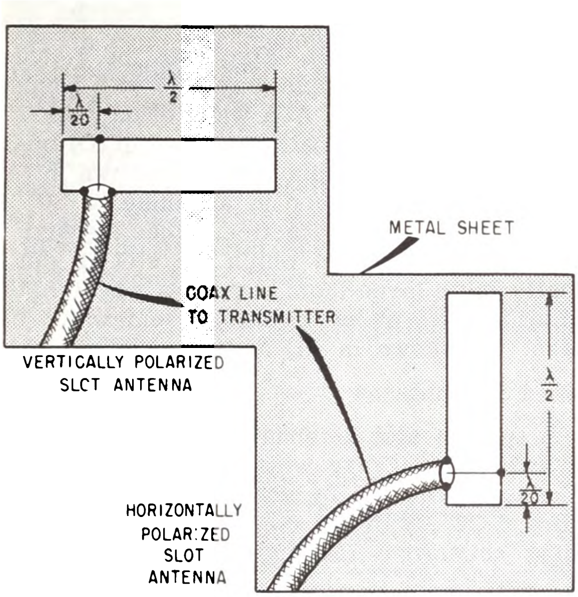
When energy is applied to the slot antenna, currents flow in the metal sheet. These currents are not confined to the edges of the slot but rather spread out over the sheet. Radiation then takes place from both sides of the sheet. In the case of the complementary dipole, however, the currents are more confined, so a much greater magnitude of current is required to produce a given power output.

From this it may be seen that the current distribution of the dipole resembles the voltage distribution of the slot, and conversely. The edges on the slot have a high voltage concentration and relatively low current distribution; the complementary dipole has a quite high current concentration and relatively low voltage.

Coaxial Feed of the Slot Antenna

A coaxial line is frequently used to feed the slot antenna. The outer conductor of the feed line is bonded to the metal sheet while the inner conductor is connected to the opposite side of the slot as shown in figure 6-21. Note that the coaxial line is not connected at the center of the slot length since a severe impedance mismatch would occur.

The impedance at the center of a slot whose electric length is a half wave is 530 ohms. This impedance is reduced to a lower value as the input connection is moved toward the end of the slot. At a point about one-twentieth of a wavelength from either end, the input impedance falls


λ/2
λ/20
METAL SHEET
COAX LINE TO TRANSMITTER
VERTICALLY POLARIZED SLOT ANTENNA
λ/2
λ/20
HORIZONTALLY POLARIZED SLOT ANTENNA

AT.454

Figure 6-21.—Feeding slot antenna with coaxial line.

to about 50 ohms. A coaxial line may thus be connected here without serious mismatch. The slot length may be increased to a full wave if it is desired to connect the coaxial line to the center of the slot. With a full wave slot, the input impedance at the center of the slot is 50 ohms.

Boxed-In Slot Antenna

Frequently, it is desired to produce radiation from only one side of the metal sheet in which the slot is cut. This is conveniently arranged by boxing in the slot with a section of waveguide. If the depth of the waveguide is a quarter wave (fig. 6-22), then the waveguide will introudce no reactance. Under these conditions, the input impedance at the center of the slot is about 1,000 ohms and the impedance at a point about one-twentieth of a wavelength from either end is about 100 ohms.

Waveguide-Fed Slot Antenna

Another convenient method of making a slot antenna radiate from only one side of the metal sheet in which it is cut is to energize the slot by means of a waveguide as shown. This does away with the coaxial feeder altogether.

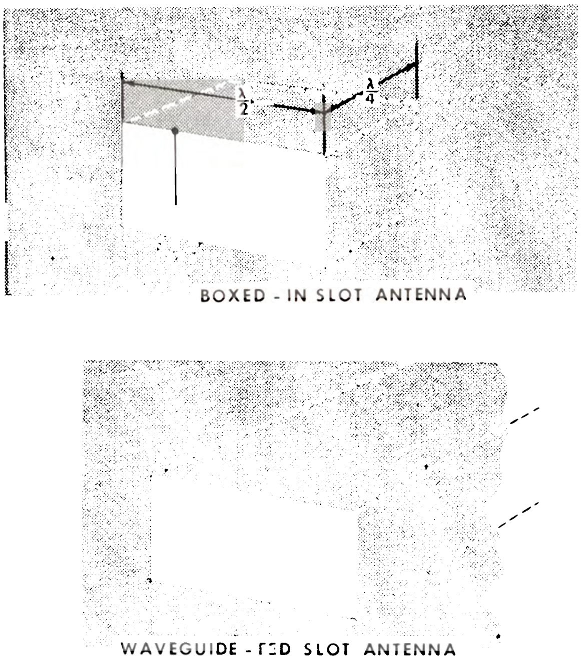


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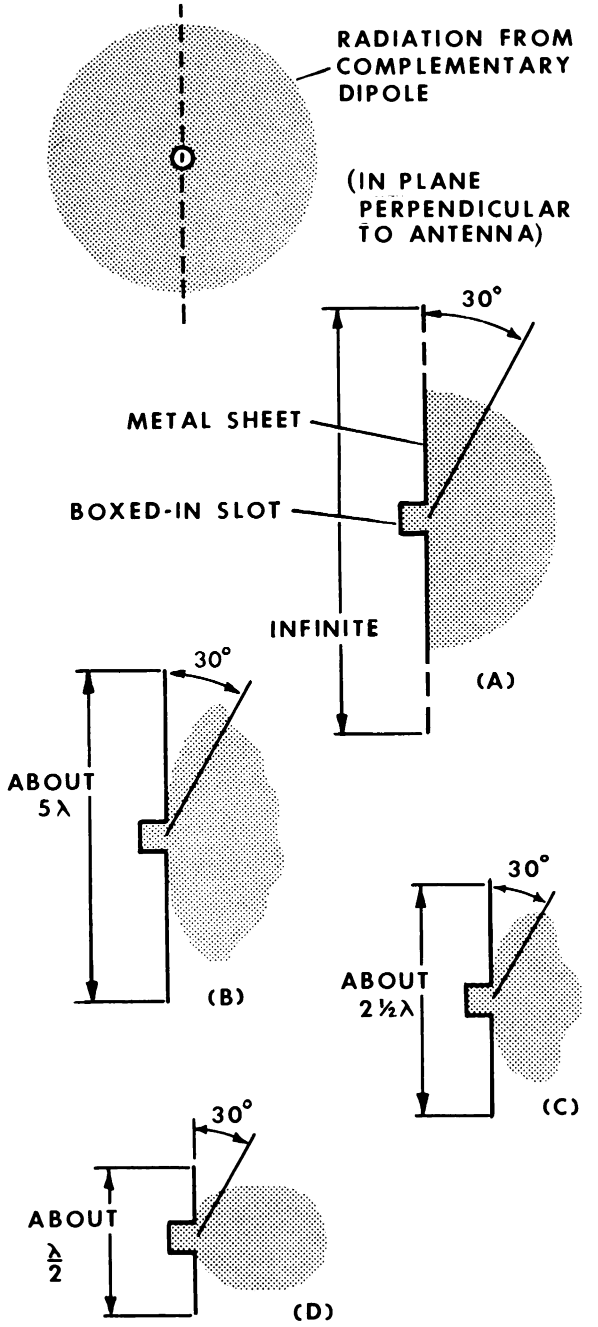
Figure 6-22.—Unidirectional slot antennas.

Radiation Patterns

It has been mentioned that the radiation pattern produced by a slot antenna is the same as that produced by a complementary dipole antenna. This is true only if an infinitely large metal sheet is used. As the width of the metal sheet is reduced, the amount of radiation that occurs at small angles to the plane of the metal sheet is reduced considerably. This is shown in figure 6-23. The radiation pattern produced by a complementary dipole antenna in the plane perpendicular to the antenna is also shown for comparison. In this pattern, you are looking at the end of the dipole. If all radiation disappeared to the left of the vertical centerline shown in the illustration, then you would have the radiation pattern produced by a boxed-in slot antenna. (See (A) of fig. 6-23.) Here you are looking along the edge of the metal sheet in which the slot is cut. The length of the slot is at right angles to the plane of the page and the radiation patterns shown are in the plane of polarization of the energy.

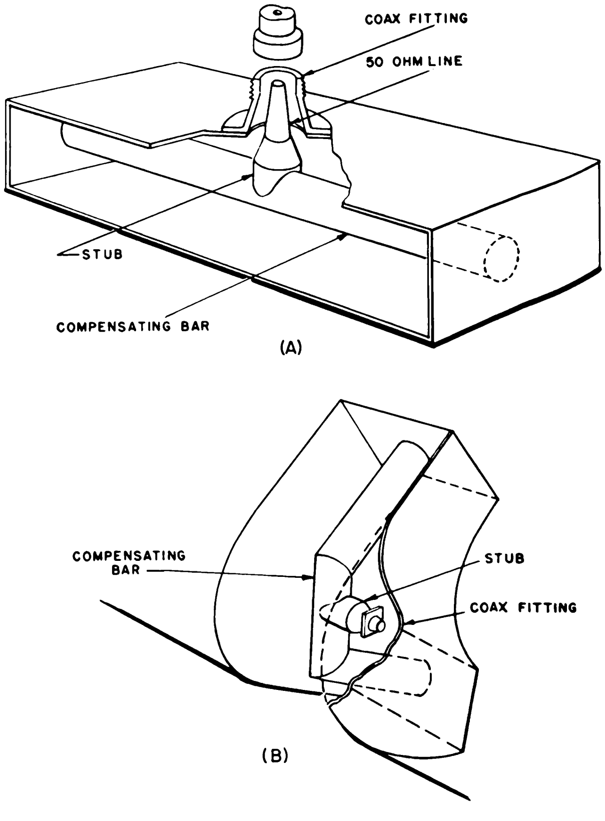


AT.456
Figure 6-23.—Radiation from boxed-in slot antenna.

If the width of the metal sheet is a little over 5 wavelengths, then the scalloped pattern shown in (B) results. As the width of the sheet is further reduced to slightly over 2 1/2 wavelengths, fewer irregularities appear in the pattern, as shown in (C). Also note the reduced radiation at a fixed angle (say 30°) with respect to the metal surface. At a width of only about a half wavelength, the pattern shown in (D) bears only a little resemblance to that shown in (A). The radiation produced at an angle of 30° is further reduced. In practice, since the size of the metal surface in which the slot is cut is usually quite large (compared to a wavelength), radiation patterns having a form somewhere between that shown in (A) and (B) are common.

T-Fed Slot Antenna

A type of slot antenna which was developed for use over a very wide frequency band and which could be fed by coaxial line is shown in figure 6-24. With the compensating bar (providing capacitive loading) and stub as shown,



AT.457
Figure 6-24.—T-fed slot antennas.

this antenna has a standing wave ratio of less than 2 to 1 over a frequency range from about 30 percent below to about 30 percent above the design center frequency when fed with 50-ohm coaxial cable. Such an antenna may be constructed in a large flat metal surface or it may be made to conform with a curved metal surface. For example, the curved slot antenna shown in (B) can be installed in the leading edge or tip of an aircraft wing. With such a severely curved large metal surface, the radiation pattern produced is quite different from that produced with a slot in a flat surface. The extent of the curvature has considerable effect on the radiation produced.

Slot Array

Still another form of the slot antenna is shown in figure 6-25. Here the large metal sheet is eliminated completely. Instead, an array of diagonal slots is cut into a length of waveguide. The slots are spaced at intervals along the waveguide so that they are excited in phase. Maximum radiation takes place in the direction indicated.

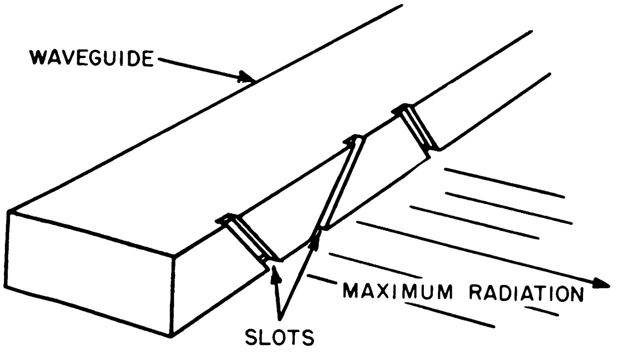


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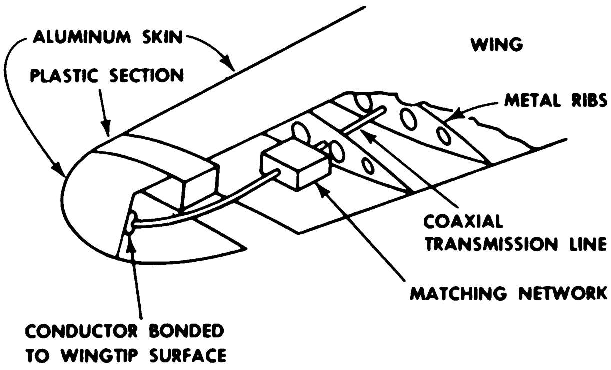
Figure 6-25.—Slot array.

SKIN ANTENNA

A skin antenna is a type of flush mounted antenna used in aircraft. Such antennas are generally used in high speed aircraft where it is necessary to eliminate the speed reducing aerodynamic drag produced by the usual types of antenna installations. The skin antenna is made by electrically isolating a portion of the metal skin of the aircraft and using this section as the radiating surface of the antenna. In one type of installation, a plastic section insulates the metal skin at the wingtips from the rest of the skin of the aircraft as shown in figure 6-26. The wingtip section connects to the receiving and transmitting equipment through an impedance matching network and coaxial cable.


ALUMINUM SKIN
PLASTIC SECTION
WING
METAL RIBS
COAXIAL TRANSMISSION LINE
MATCHING NETWORK
CONDUCTOR BONDED TO WINGTIP SURFACE

AT.459

Figure 6-26.—Wingtip antenna.

The range of a skin antenna approximates that of fixed wire antennas for the same frequency coverage. Although the illustration shows a wingtip installation, skin antennas can also be made a part of suitable tail or fuselage surfaces. The radiation patterns depend on the operating frequency, the size of the radiating surface, and the location of that surface on the aircraft.

Other types of flush mounted antennas which find wide use in VHF and UHF aircraft communications and radar installations consist of loops, dipoles, and parasitic and driven arrays encased in plastic housings or canopies forming the tip or a part of the surface of a wing, elevator, stabilizer, or nose.

UHF BROADBAND ANTENNAS

The so-called "broadband antenna" is a representative of a class of low-Q antennas that will operate with fairly constant effectiveness over a wide range of frequencies. Electronic countermeasures (ECM), frequency modulation (FM), pulsed radar altimeters, and other equipments have used this type antenna effectively.

In order to be of maximum effectiveness, passive ECM must receive and respond to any signals over a wide frequency range. This reception must be rapid, with a minimum of tuning adjustment.

Basic UHF Antenna

The antenna itself is normally a half-wave dipole, made thick and stubby in order to give the antenna a low inductance, a low L-to-C ratio, and the low Q that results from these. Being a tuned circuit, the antenna will have a wider frequency response with less gain than an equivalent antenna with a higher Q. Another factor that will add to the wide uniform response is the method of support. Normally this support will be a quarter wave shorted section of transmission line. In addition to the insulating qualities of the transmission line section, the support may be used as an impedance matching device, and also as a tuning stub.

Since the antenna acts the same as an open-ended quarter-wave section of transmission line, any increase in frequency will tend to cause the antenna to become inductive, and the support to become capacitive. This opposing action results in the antenna appearing resonant over the wider frequency range. Lowering the frequency will cause opposite actions, and broader response.

The assembly will normally include built-in impedance matching devices which are relatively insensitive to frequency variations.

The antenna itself may be a half-wave dipole, of which there are many types. The type that provides the ultimate in broadband response is the flared coaxial antenna of the type shown in figure 6-27 (A). The inner and outer conductors are both flared, but in order to maintain a constant impedance throughout the full range of frequencies, the ratio of the inner to outer diameter is maintained constant. The more gradual the flare of the diameters, the less reflection of mismatched impedances, and the more constant the efficiency of the antenna.

By folding the outer conductor of the coaxial antenna to form a ground plane, and shaping the inner conductor to a teardrop configuration (as in (B)), an antenna is obtained that has a frequency response nearly as good as the original broadband type discussed above.

The actual radiator of the broadband antenna may take any of several shapes, depending on

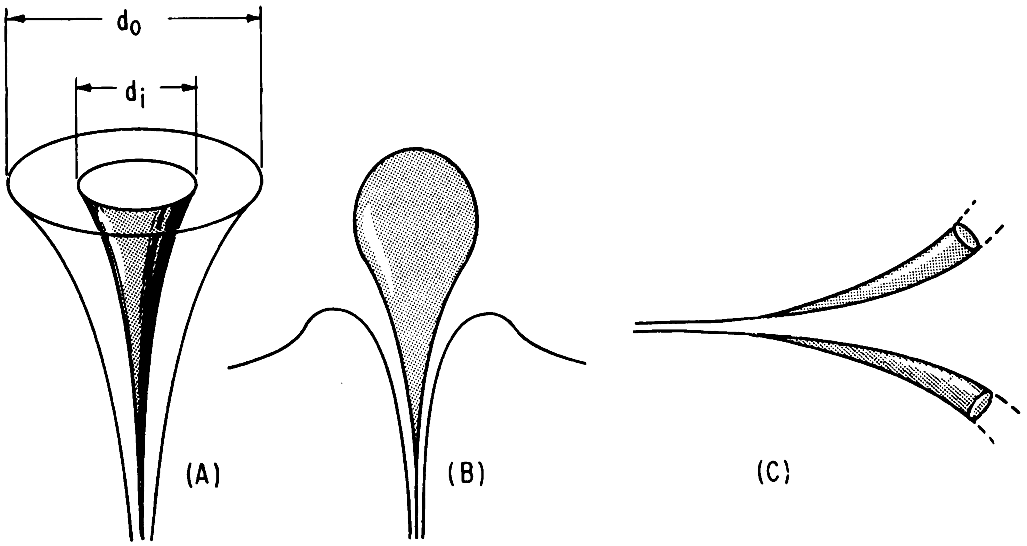


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Figure 6-27.—Broadband antennas.

the desired broadness of the band, directional characteristics, impedance, etc. In general, the greater the thickness of the radiating element, the broader the bandpass. Thus, radiators having conical or cylindrical shape are less broad than those previously discussed, while the thin stub (or whip) is even more narrow in its frequency response.

In the coaxial feed and antenna system, the ratio of diameters (outer to inner) is sometimes changed. When this is done, the resulting impedance mismatch reflects energy back down the line. This mismatch may be fairly abrupt, being more so as the antenna is made thinner or as the change in the ratio is made more abrupt. The frequency band is determined by those frequencies at which the impedances are sufficiently matched and the reflection cancel.

The antenna required for a broadband response could also be developed from the two-wire transmission line (as shown in (C) of figure 6-27,) but the frequency response is not quite so broad as for the equivalent coaxial antenna.

Blade Antenna

An ultrahigh frequency, streamlined, blade shaped broadband antenna for general purpose use over the 225- to 400-megahertz range is shown in figure 6-28 (A). An antenna of this shape may consist essentially of a near quarter-wave stub fed through the base, or it may be a sleeve type antenna. It is designed for mounting on the exterior skin of the aircraft, and so it is streamlined for high speeds. Its cross sections take the form of ellipses on the leading half of the body, and of parabolas on the trailing half. The resulting form has minimum drag effect.

This antenna is usually a single self-contained unit. No accessories are required other than those for mounting and connecting.

A single broadband antenna of this type may be connected to two or more pieces of equipment operating on different frequencies within the range of the antenna. When this is done, it is necessary to use bandpass filters in series with the antenna cables to isolate the equipments.

Cone Antenna

It frequently becomes desirable for a transmitting or receiving antenna to operate over a wide band of frequencies. This is especially true in electronic countermeasures and airborne communication equipment. In order to operate over a wide band, it is necessary that the characteristics of the antenna system be such that the radiation pattern is not appreciably changed over the frequency range involved. It is also necessary that the standing wave ratio be held to a minimum in order to prevent excessive losses.

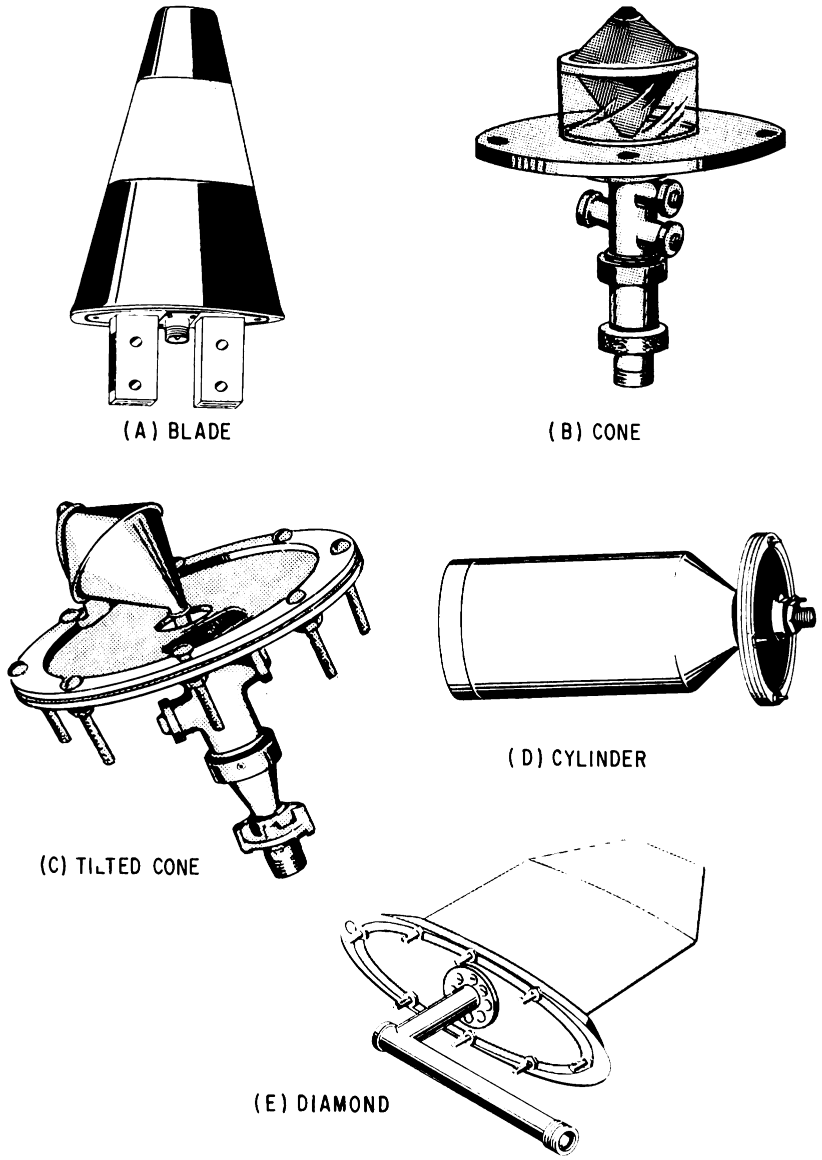
The impedance of resonant wire antennas will vary with frequency, thus they will function adequately over only a narrow frequency band. As previously stated, it is possible to maintain a uniform impedance over a wider frequency band by increasing the diameter of the antenna elements. This increase in diameter reduces the Q of the resonant system and this in turn causes a reduction in the reactive energy stored in the E and H fields adjacent to the antenna.

A cone antenna is a good example of increasing the diameter in order to obtain wideband operation. The bandwidth of this type antenna can be further increased by the use of compensating reactances. By the use of these series and shunt reactances, it is possible to increase the operating frequency range of the antenna as much as six times.

Figure 6-28 (B) and (C) show two cone type high frequency antennas for use with ECM equipment. In each of these, the electrical connections are brought to a receptacle at the bottom of the antenna. The antenna flange is designed to be mounted flush with the skin of the aircraft. A Plexiglass dome or blister is used to cover the antenna in order to afford protection and to reduce wind resistance.

The antenna illustrated in (B) should be mounted vertically to receive vertically polarized waves and horizontally to receive horizontally polarized waves. The antenna in (C) is similarly constructed except that the conical pickup element is mounted at an angle of 45° to the mounting flange. This permits reception of either horizontally or vertically polarized waves for a single mounting position.

Some antennas of this type have a high-pass filter incorporated in their assembly to attenuate all frequencies below their designed operating range. Signals below the operating range are filtered out and do not reach the equipment. It is important when selecting antennas of this type (especially for ECM equipment) that a close check be made, since an antenna that is



(A) BLADE

(B) CONE

(C) TILTED CONE

(D) CYLINDER

(E) DIAMOND

AT.461

Figure 6-28.—Typical aircraft antenna assemblies.

equipped with this type filter will pick up a negligible amount of energy below its operating range.

CYLINDRICAL.—A modified cone antenna is shown in figure 6-28 (D). This assembly consists of a cylindrical antenna with an inverted cone shaped base fitted into a mounting flange. It is designed as a jamming transmitter antenna and covers the frequency range of 200 to 550 megahertz.

DIAMOND.—Another variation of the cone antenna is illustrated in figure 6-28 (E). It is a flat, diamond shaped metal plate enclosed in a streamlined plastic housing and is omnidirectional.

An antenna of this type, when operated at about 1,000 megahertz, will provide efficient operation over a bandwidth of approximately 200 megahertz. Since this antenna is made of a flat piece of metal, it may be mounted in an airfoil type plastic housing that offers little wind resistance. This is especially desirable for high speed aircraft.

The radiator is made diamond shaped, in order to obtain broadband frequency characteristics, and is vertically polarized. Since it is end fed, its impedance is comparatively high (140 ohms) and a matching section of transmission line is used to match this impedance to the 51 ohm transmission line. This section, which is a three-quarter-wave line, properly matches the impedances of the antenna and the antenna cable, and provides a low standing wave ratio along the cable. The antenna requires no adjustment.

Polyrod Antenna

Figure 6-29 shows a polyrod antenna that consists of a slender, tapered rod of special plastic. This rod is cemented to a piece of standard waveguide that is flared to match the square dimension of the large end of the rod. The principal mechanical features of this antenna are its streamlined aspect, its small size, and light weight.

It can be shown experimentally that very high frequency radio energy can be made to travel along a rod made of material having good dielectric properties in much the same way as light travels along a lucite rod. Some of the light traveling along the lucite rod is emitted from its longitudinal surfaces. Similarly, some of the radiofrequency energy traveling along the dielectric rod is radiated from its longitudinal surfaces.

By appropriately tapering the rod, the amount of energy radiated per unit length may be made approximately the same throughout the length of the rod. In doing so, an end-fire antenna is created which is roughly analogous to a linear array of dipoles spaced a quarter wavelength apart and fed at successive 90° intervals. For such an antenna array, the net energy radiated broadside to the rod will be a minimum. The rod, as seen from a point in a forward direction, will appear to be radiating a cigar shaped beam of energy.

HORN ANTENNA

The horn antenna provides a method of matching the impedance of waveguides to free space, and at the same time providing desired beam characteristics. Normally, the radiation pattern of an open-ended waveguide is broad in both the vertical and the horizontal planes. It is also an inefficient radiator system because of the mismatch between the waveguide antenna and free space. The evolution of the horn came about as a result of the effort to minimize the reflections that occur when a straight piece of waveguide radiates into space. By flaring the open end of the waveguide, the RF energy in the guide does not encounter such an abrupt impedance change when it reaches the end of the guide; hence, reflections and standing waves are minimized.

If the waveguide is flared out at a gradual angle, a horn antenna is obtained. The flare must be gradual so as to permit a better match between antenna and free space. At the same time, a sharper beam is obtained when a flared horn is used.

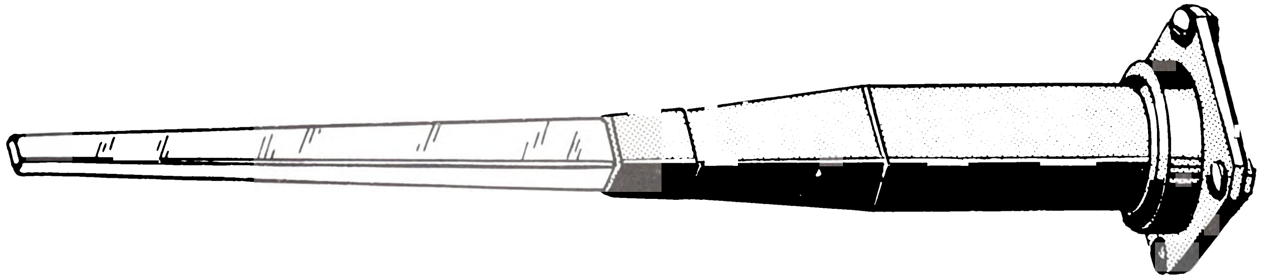

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Figure 6-29.—A polyrod antenna.

The horn is very practical at microwave frequencies since at these frequencies its physical size is not prohibitive. Since a resonant element is not involved, this type antenna is capable of wideband operation. Horn antennas used in aircraft installations produce beam patterns that are not highly directive. In order to produce a highly directive beam at lower frequencies, the antenna would have to be longer than practical for aircraft.

The horn antenna may be used with either circular or rectangular waveguides, and the same general considerations will apply: the longer the flare of the horn, the higher the gain and the narrower the beam width. For both circular and rectangular horns, the flare angle for the narrowest beam is between 40° and 60°. Generally speaking, the gain of a horn is less than that of a parabolic antenna. In order for the horn to have the same gain as a parabolic antenna, the horn must be much longer, which soon proves to be a big disadvantage.

A sectoral type horn antenna is illustrated in figure 6-30 (A). Its field distribution is spherical in shape and depends upon the mode of operation of the waveguide feeding it and the flare angle of the horn. The spherical shape of the wavefront becomes flatter (elliptical) as the flare angle of the horn decreases. This horn has the greatest degree of directivity in the plane of the widest dimension.

Two other types of horns to which the principles just described apply are shown in (B) and (C). The pyramidal horn (B) has equal directivity in both the vertical and horizontal plane. The conical horn (C) produces a conical beam pattern.

For horn antennas (as well as for dipole arrays and reflectors), a rule that may be kept in mind is that the larger the aperture of the waveguide or the larger the area of the array, the greater will be the gain and directivity. Since a large aperture is desired at the mouth, the length of the horn may become unwieldy if the gradual flare requirement is to be incorporated in the design.

However, a recent development in antenna design has made possible the use of horn antennas having a much larger equivalent size than was formerly practicable. This new type antenna has been called the JELLY-ROLL ANTENNA, due to its configuration. Effectively, it is the same as a conventional horn antenna rolled from the feed end toward the aperture end like a jelly roll. The resulting cylindrical shape uses less space than the conventional horn with the same size feed, the same angle of flare, and the same size aperture. Therefore, this saving in size could be used to good advantage by increasing the size of the aperture, with the resultant increase in directivity and gain.

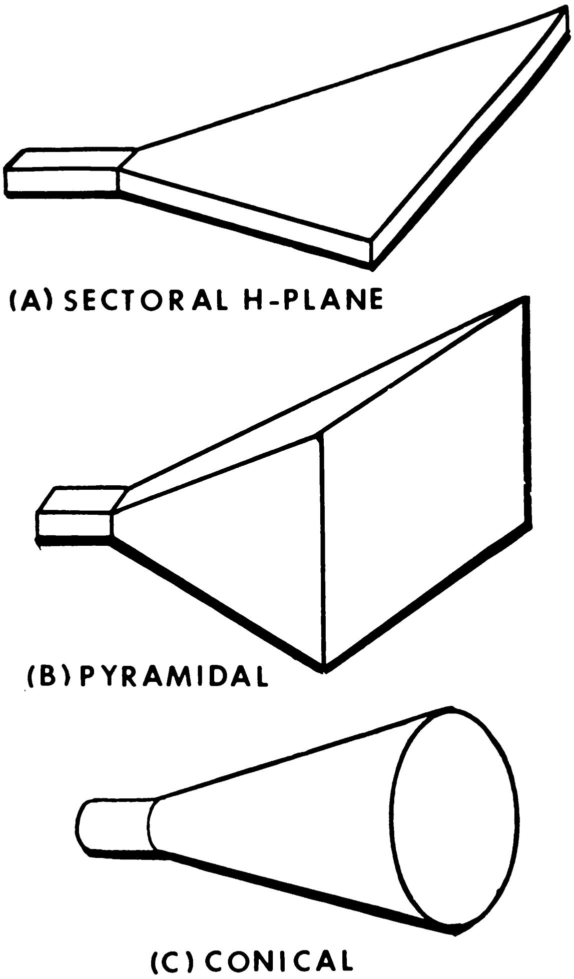

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Figure 6-30.—Horn antennas.

Another method of improving the directivity and gain of a horn antenna is by the use of electromagnetic lenses to focus the beam in much the same manner that the light beams are focused by an optical lens.

MICROWAVE LENSES

A lens is a structure substantially transparent to microwaves, but which inserts a phase change over the cross section of the exit side of the lens to make the microwaves coverage or diverge. The lens is placed in front of a point source of RF energy, such as a feedhorn. The feedhorn is located at the focal point of the lens, and radiates spherical waves which are concentrated into a beam as they pass through the lens.

The focusing action of the lens is due to its ability to take the spherical wavefront of the energy transmitted by the horn and transform it into a plane wavefront. This is accomplished by changing the velocity of portions of the wavefront producing a flat wavefront. A wavefront that is flat will possess extremely good directivity. The lens may be made of plastic or it may consist of conducting strips of metal.

The explanation of microwave lenses can be better understood if we first consider a little background information. Then we will see that the microwave lens and its principles of operation are not strangers to us. Microwaves are similar to light in that both (like many other types of energy) travel in waveform. Consequently, both obey the physical laws of wave transmission. Although the primary purpose of an RF transmission line is to guide the transfer of energy from one place to another, in so doing the transmission line has other characteristics which may be useful in certain cases. For example, if a voltage is applied to the input terminals of a line, a definite amount of time passes before the voltage appears at the output terminal. In other words, the line has the ability to delay the transmission of voltages and currents. The time delay is determined by the length of the line and its characteristics, R, L, and C. The time delay of a transmission line has many applications in radar timing. The artificial transmission lines used in radar employ this factor.

However, there is nothing in the physical laws of microwave transmission that says we must have a material conductor. The same laws apply to propagation of RF waves in air or in a vacuum. The velocity of wave propagation is determined by the characteristics of the medium through which it travels.

Microwave lenses are of two basic types. One type is the waveguide, or conducting type, shown in figure 6-31 (A). The other type is the dielectric, or delay type shown in figure 6-31 (C).

A sectoral horn with a conducting-strip lens is shown in figure 6-31 (A). This type accelerates wave transmission as it passes through the lens. It consists of flat metal strips placed parallel to the electric field of the wave and spaced slightly in excess of one-half of a wavelength. To the wave these strips look like waveguides with each hypothetical waveguide having a dimension in a direction perpendicular to the electric field corresponding to the spacing between the parallel strips. The velocity of phase propagation of a wave is greater in a waveguide than in air.

As you can see, the strips near the sides of the horn form longer sections of waveguide than those in the center. Since the lens is effectively concave (B), the phase velocity is progressively increased from the center of the horn toward the sides as the lengths of the individual waveguide sections increase. The outer portions of the transmitted spherical wavefront are accelerated for a longer period of time than the inner portion. Therefore, this wavefront will emerge at the exit side of the lens aperture as a flat-fronted wave. This waveguide type lens is frequently sensitive (because of the change in phase velocity of waves in a waveguide with a change in frequency), so frequency stability of the transmitter is an important consideration in equipments where it is to be used.

A dielectric or delay type lens is shown in (C) of the figure. The delay lens, as its name implies, slows down the phase propagation as the wave passes through the lens. This lens is convex, and consists of dielectric material. The delay in the phase of the wave passing through the lens is determined by the dielectric constant (or refractive index) of the material. In this case, the inner portion of the transmitted wave is decelerated for a longer interval of time than the outer portions. (See fig. 6-31 (D).)

Many lenses of this type use artificial dielectrics consisting of conducting rods or spheres that are small compared to the wavelength.

In a lens antenna the exit side of the lens can be regarded as an aperture across which there is a field distribution. This field acts as a source of radiation just as fields across

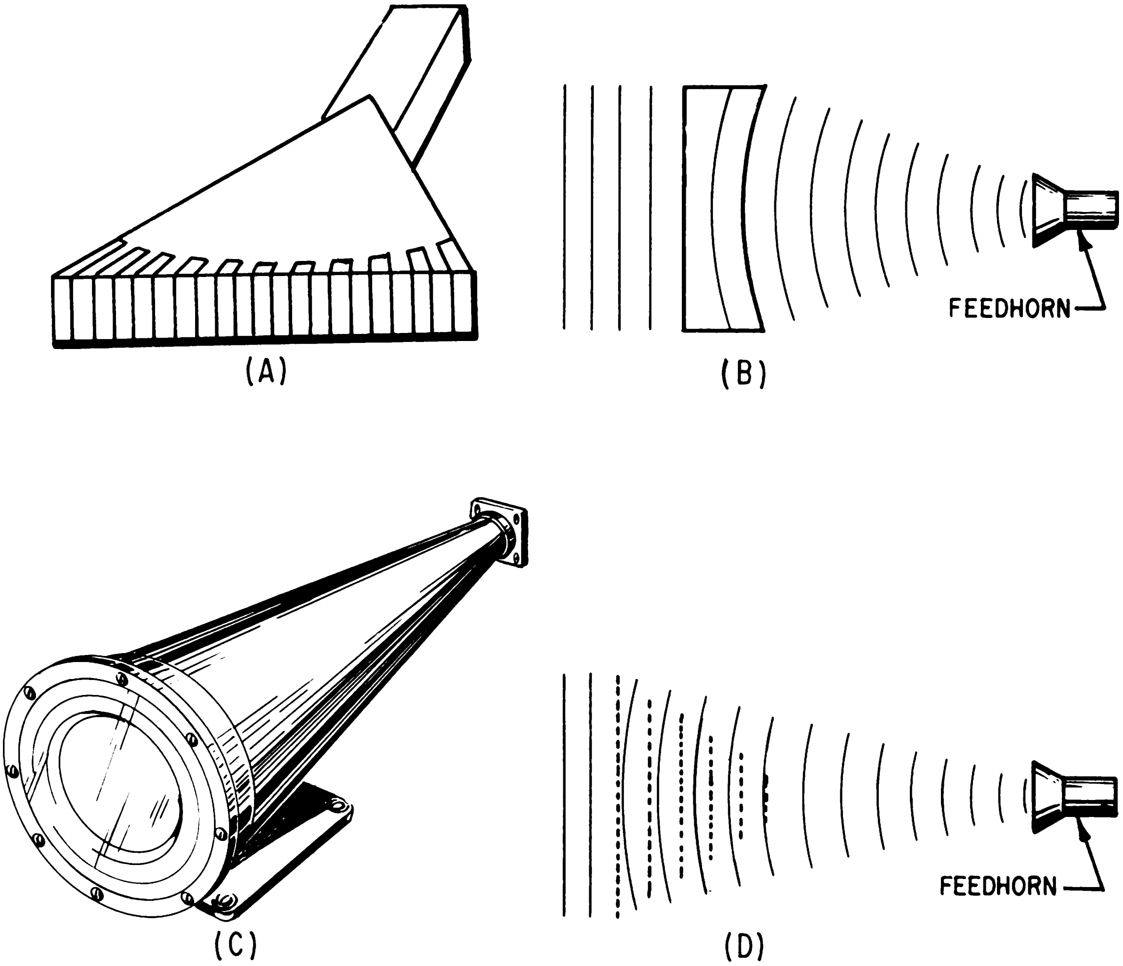

Figure 6-31.—Microwave lenses.

the mouth of a reflector or horn. For a returning echo the reverse effects take place in the lens.

It can be seen that the reflector uses the law of reflection while the lens uses the law of refraction. The rear feed arrangement of the lens antenna eliminates spillover radiation in the backward direction. Also, this arrangement puts the radiator out of the path of the beam, thus reducing shadows.

The plastic type lens, shown in figure 6-31 (C), is affixed to a conical horn type antenna. This particular antenna produces a beam width of 18° at half-power points and has a gain of approximately 100. The lens is effective in reducing the sidelobe intensity by retarding the phase of the energy leaving through the center of the lens. This causes the energy to leave the horn in a plane of constant phase.

While the two types of lens produce the same results they operate in somewhat opposite manner. The plastic lens retards the phase of the energy at the center and the conducting-strip lens accelerates the phase of the energy at the edge.

It is interesting to compare the characteristics of this antenna with those of the polyrod shown in figure 6-29. While the halfpower beam width of the horn is 18° , that of the polyrod is 25° . However, the spurious radiation from the polyrod is of greater magnitude than that from the horn. These factors cause the polyrod to be less efficient than the horn, but nevertheless, in some applications, it is more desirable because of its mechanical features.

MONOPULSE ANTENNA

The methods of radar scanning covered in Basic Electronics (NavPers 10087-C) and Aviation Electronics Technician 3 & 2 (NavPers 10317-D) are sometimes called sequential lobing, because target information must be gathered from a series or sequence of pulses. The high speed response and fine degree of accuracy required of tracking radars in modern high speed weapons systems have made this system unsuitable for some applications. Another scanning technique, called MONOPULSE or simultaneous lobing, can obtain information on target range, bearing, and elevation from a single pulse. This system is presently used in some of the newer type fire control and tracking radars.

For target tracking, the radar discussed here produces a narrow circular beam of pulsed RF energy at a high pulse repetition rate. Each pulse effectively is divided into four signals which are equal in amplitude and phase. The four signals are radiated at the same time from the four feedhorns as indicated in figure 6-32.

The radiated energy is focused into a narrow beam by a microwave lens. Energy reflected from the target is refocused by the lens into the feedhorns. The total amount of energy received by each feedhorn is determined by the position of the target with respect to the center of the beam. This is illustrated for four targets at different positions with respect to the beam axis. Notice that a phase inversion takes place at the microwave lens similar to the image inversion in an optical system.

The amplitude of returned signals received by each horn is continuously compared with those received in the other horns, and error

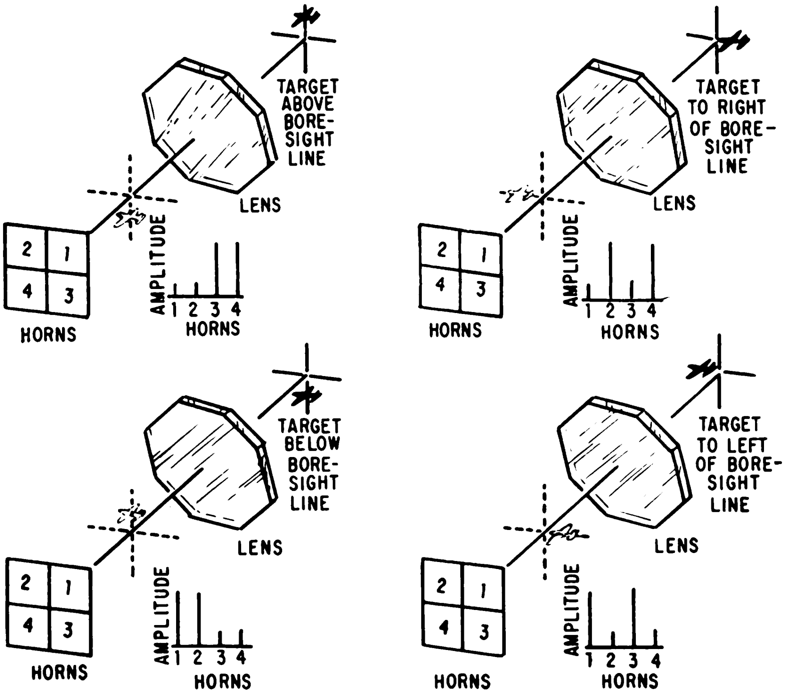

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Figure 6-32.—Monopulse technique.

signals are generated which indicate the relative position of the target with respect to the axis of the beam. Angle servocircuits may be used to receive these error signals and correct the position of the radar beam to keep the beam axis on target.

The BEARING (azimuth) signal is made up of signals from horns 1 and 3 (added) and from horns 2 and 4 (added). By waveguide design the sum of 2 and 4 is made to have a 180° phase relation with the sum of 1 and 3. These two sums are combined, and the bearing signal is the difference of (1+3) — (2+4). Since the horns are positioned as shown in the figures, the relative magnitudes of the horn signals give an indication of the bearing error.

The ELEVATION signal consists of the signals from horns 3 and 4 added (with 180° phasing) to 1 and 2; i.e., (1+2) — (3+4).(The 180° phasing accounts for the negative sign.)

The RANGE (sum) signal is composed of signals from all four feedhorns added together in phase. This range signal is also used as a reference signal for the bearing and elevation error signals. The bearing and elevation error signals are compared in the radar receiver with the reference (range) signal. The output of the receiver may be positive or negative pulses, depending on direction of error, with a magnitude proportional to the angle between the boresight (beam) axis and a line drawn to the target. Of course, if the target is directly on the boresight line, the output of the receiver is zero, and no angle tracking error is produced.

In the monopulse system, certain problems are inherent, and suitable provision must be made for their solution. Among the most important of these problems are:

1. A single magnetron output must be fed to all four antenna feedhorns, and these must be in phase and of equal magnitude.
2. Echo signals received by the feedhorns must be fed to the receiver channels with the proper phasing and magnitude.
3. Range (reference) signals are to consist of the echoes from all four horns, added in phase.
4. Elevation angle error signals must reflect the difference in magnitude and the polarity of the difference in the sums of the signals from horns 1 and 2 and from horns 3 and 4, added in phase.
5. Bearing angle reference signals must reflect the difference in magnitude and the resulting polarity of the sums of the echoes from horns 1 and 3 and from horns 2 and 4, added in phase.

These problems are solved in part by the use of the MAGIC-T COUPLER.

MAGIC-T COUPLER

As shown in figure 6-33 (A), a magic-T coupler consists of four energy paths with a common junction. For the following discussion, assume that the magnetron's output is fed through a TR/ATR duplexer to path 3, and that the return echo signals present in path 3

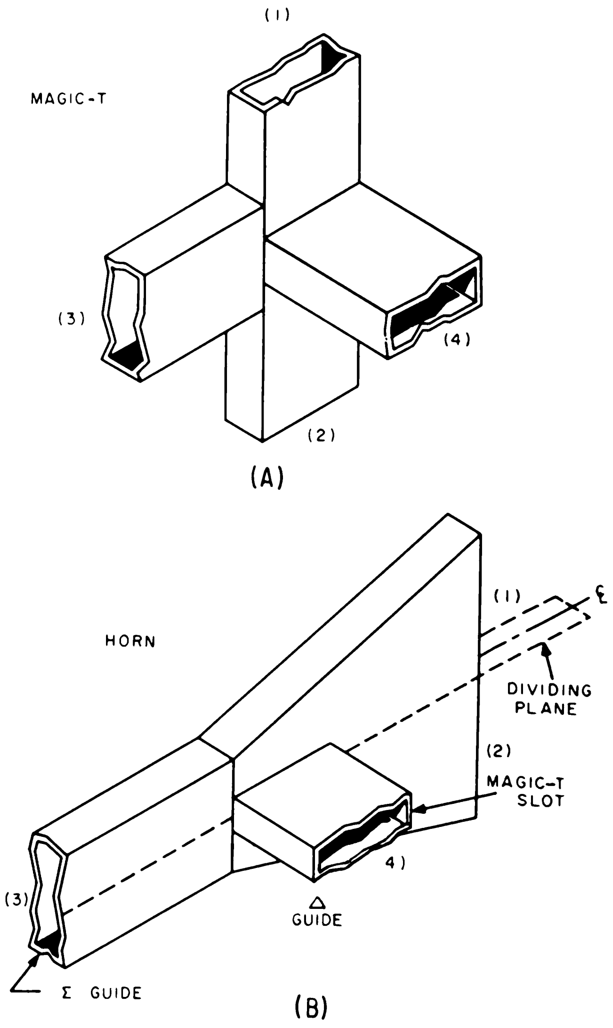

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Figure 6-33.—Magic-T coupler, basic drawings.

are fed through the same duplexer system to a reference channel in the receiver. Further assume that paths 1 and 2 are fed to two of the antenna feedhorns, and that path 4 is fed into another channel of the receiver (either elevation or bearing).

Transmitted energy in path 3 (fig. 6-33 (A)) is propagated in equal amounts in paths 1 and 2. None is propagated in path 4 since no field strength difference exists across its face (which is at right angles to the transverse electric mode). Target returns appearing at paths 1 and 2 in equal field strengths are therefore propagated in path 3 but not in path 4 since, again, no field strength difference exists across its face. However, if the received signals appearing at paths 1 and 2 are not of equal field strength, a potential difference does exist across the face of path 4, and energy is propagated into this waveguide in an amount proportional to the difference in field strengths between paths 1 and 2; that is, a potential difference must occur across the face of path 4 in order for energy to be propagated in this path. A potential difference will occur across the face of path 4 when there is an imbalance between the signal strength from path 1 and path 2. The amount of energy propagation in path 4 is dependent upon the magnitude of this imbalance in signal strength between path 1 and path 2.

If there is energy propagated in path 4, its phase relationship to the reference (sum) signal is determined from which path (1 or 2) the greatest signal is supplied and by the construction of the magic-T coupler.

In airborne radar systems, it is frequently necessary to develop an error signal in only one geometric plane—either bearing or elevation. Figure 6-33 (B) illustrates the principle applied in one typical height finding (elevation) application. Note that a single horn radiator is used to effectively produce both the up and the down signals. Although there is no physical surface separating the paths 1 and 2, the positioning of the magic-T slot (path 3) along the boresight axis of the feedhorn effectively divides the horn into two identical halves.

The feedhorn effectively comprises two functional antenna sections—one for the sum channel (Σ guide) and one for the difference channel (Δ guide). Note, however, that only the sum channel (path 3) is used for transmission.

The primary receiving channel is the sum waveguide and feedhorn combination. The horn is an impedance matching device used to propagate the transmitter output pulses into the atmosphere (and to shape the pattern radiated against the reflector). Echoes reflected from the targets enter the open end of the feedhorn as a single receiving pattern, and are propagated through the waveguide to produce the sum video signals. The secondary receiving element is the difference channel (Δ guide) and consists of the magic-T slot (path 4) which is incorporated into the horn configuration.

Each half of the horn is effectively a separate waveguide (or receiving antenna) having its own sensitivity pattern. When the target is situated along the boresight axis of the antenna, equal sensitivities exist for paths 1 and 2, so no difference signals are propagated. For targets above the boresight, the upper half of the antenna is somewhat more sensitive to echoes than the lower half, and will respond with a stronger signal than the lower. This results in a difference in field strength between the signals in paths 1 and 2 of the magic-T.

Because of the difference in these field strengths, a potential difference exists across the magic-T slot (path 4), and a small amount of energy is propagated in the guide. The amount of energy so propagated is directly related to the difference of the field strengths in the input arms.

When a target is located below the boresight axis of the feedhorn, the lower half of the antenna is more sensitive to radar echoes than the upper half.

The phase relation of the difference and sum signals is determined by the physical position of the magic-T slot with respect to the opening into the sum channel waveguide. The antenna configuration is chosen so that a difference signal, which is caused by greater energy in one channel, is in phase with the sum channel reception, while the reverse energy conditions results in the opposite phase. Only a small portion of the total received energy is coupled to the difference channel; the major portion is propagated in the sum channel, and is used as the target display in the indicator.

There are numerous variations of nonpulse radar systems in use in naval airborne electronics applications. For specific details on the peculiarities of an actual type equipment, consult the applicable Maintenance/Service Instructions manual for that equipment or aircraft.

CHAPTER 7

UHF AND MICROWAVE TECHNIQUES

The increase in congestion of the communication channels below 30 MHz and the special advantages of the shorter wavelengths in the very high and ultrahigh frequency bands have led to increasing use of these parts of the RF spectrum. It must be understood that the behavior of radio waves at the VHF, UHF, and microwave frequencies is very different from their behavior at lower frequencies, and the differences are extremely important. This chapter begins with information on the fundamental differences in the behavior of radio waves in this frequency range and the reasons for these differences. The distributed properties of inductance, capacitance, and resistance associated with conductors are discussed next, because their effects must be understood before the action of electronic circuits operating at these frequencies can be comprehended. It is also necessary to understand the changes that occur in the behavior of lumped-property components, such as inductors, capacitors, and resistors, when they are operated in the VHF/UHF/microwave region. The theory and operation of a number of components and circuits employed at these frequencies are also discussed. A detailed discussion of klystrons and magnetrons is presented in Basic Electronics, NavPers 10087-C, Vol. 2. These two components are used extensively in microwave equipment.

ADVANTAGES OF USING HIGH FREQUENCIES

WAVELENGTH VERSUS PROPAGATION AND EQUIPMENT SIZE

The upper limit for radio signals that can be returned effectively to the surface of the earth by the ionosphere is about 30 MHz. Therefore, 30 MHz was chosen as the low frequency limit of the VHF band. This 30 MHz dividing line is not an abrupt one, because there is no abrupt change in the ability of the ionosphere to return the waves to earth as the frequency is increased. This action of the ionosphere takes place over a region of the frequency spectrum with its center at about 30 MHz. The band of frequencies affected by the ionosphere may occasionally move higher or lower by considerable amounts.

The 300 MHz dividing line between the VHF and UHF bands and the 3,000 MHz upper limit of the UHF band likewise are more or less arbitrary and are agreed upon for convenience. Again, these dividing lines are not abrupt. The limits should be thought of as transition regions, centering on those frequencies.

At 30 MHz and above, the ionosphere does not return radio waves to the surface of the earth very effectively, except under rather unusual conditions. This limits the effective range of radio communication and radar coverage in these frequency bands to points not far beyond the optical horizon as seen from the transmitting antenna. At first this was considered a serious limitation because most of the emphasis was on long distance communication, far beyond the horizon. It soon was realized, however, that the shorter wavelengths could be used for covering relatively local areas. This made some additional lower frequencies available for long distance communication.

Because propagation of these shorter radio waves does not reach points on the surface of the earth beyond the horizon, stations can operate on the same assigned frequency without interference, if they are separated far enough geographically. This provides reliable short range communication and is widely used in naval operations at sea, for convoy communications, for communication between ships and aircraft, and for communications between aircraft.

A second effect of the decrease in wavelength as the frequency is increased is related to the phenomenon of radio wave reflection. All electromagnetic waves, such as radio, light, and infrared radiation, can be reflected but how well they are reflected depends on a number of different factors. One factor is the relationship between the length of the wave and the physical size of the reflecting object. The AT needs to concern himself with this phenomenon because it is one of the basic principles on which radar operates, and its importance can hardly be exaggerated.

Another factor directly related to wavelength is the physical size of the equipment used to generate the RF energy, and the antenna needed to radiate it effectively. Both of these factors can be made smaller in direct proportion as the wavelength is made shorter. Obviously, equipment for the shorter wavelengths can be made smaller and more compact because of this relationship between physical size and wavelength.

Aside from the factors of size and weight, these frequencies are highly applicable to radar equipment for they produce better target echoes and make possible the detection of smaller targets. The size of the target that radar can detect depends mostly on the frequency. In general the higher the frequency, the smaller the target that the radar can detect. A target gives the best echoes when its size is about one-half the wavelength (or some multiple on the wavelength) at the frequency being transmitted. If the target is much smaller than a wavelength, the intensity of pulse that it reflects is low. However, as the operating frequency is increased, the wavelength becomes smaller making it possible to detect smaller targets.

DISTRIBUTED PROPERTIES

Distributed properties may be defined as the inductance, capacitance, and resistance uniformly spread along each unit length of any circuit element, plus the inductance, capacitance, and resistance existing from each conductor to ground and to other objects. For example, a 1/4-inch rod of copper, 4 inches long, placed in free space where no outside influence could act upon it, would be found to possess small but definite values of inductance, capacitance, and resistance. If the conductor were cut in half, each part would possess exactly half the values previously found. In other words, the distributed properties are uniform as long as the conductor itself remains uniform in cross sectional size, shape, and conductivity, provided that no external influences exist. If the conductor is not uniform, the distributed properties still exist, but their distribution is not uniform.

When a conductor is placed in an actual circuit, it possesses these self-contained distributed properties, and may or may not possess additional distributed properties caused by its proximity to ground and to other components in the circuit. Distributed properties exist in all conductors and conducting surfaces, even in the leads and other parts of the lumped-property circuit elements (capacitors, coils, resistors), which are manufactured to provide definite amounts of the properties. When used in practical circuits at VHF/UHF/microwave frequencies, however, the distributed properties of inductance, capacitance, and resistance in a given conductor actually are not fixed amounts or constants, but slowly change in value as the frequency changes.

At frequencies below 30 MHz, it is practicable to ignore distributed, or stray, circuit properties, except in circuits such as resonant sections of transmission lines or antennas. Above 30 MHz, the effects of distributed properties upon practical circuits can no longer be neglected, because of the relationship between the physical size of the circuit components and the wavelenghts. At 3 MHz, for instance, one wavelength is 100 meters long, in comparison with which a 6-inch length of wire is very short. When the wavelengths become relatively short, as the frequency increases, it becomes physically impossible to scale down the parts of the electronic circuit and keep them small in relationship to wavelength. Even where such a size reduction is possible, the power handling ability of the circuit is reduced in proportion. As a result, much of the usefulness of the device is lost.

When the operating frequency increases, the various losses that reduce circuit efficiency increase, making it desirable to use circuit arrangements and elements that have lower built-in losses. So far it has been found impossible to construct lumped-property elements that are pure and do not contain small distributed values of the other two properties. As the working frequency increases, the effects of the unwanted distributed properties cause increased losses, with the result that the efficiency drops. In circuits utilizing distributed properties, losses are lower than in the same circuits constructed of lumped-property elements, because it is possible to use conductors of proper size and shape to minimize RF resistance and because the dielectric is usually air. The result is that better circuit stability and efficiency are achieved by using the distributed properties.

Distributed Inductance

The term "distributed inductance" refers to the self-inductance distributed along the length of any type of conductor, whether it is or is not meant to act as an inductor. Inductance, as defined in Basic Electricity, NavPers 10086-B is the property of a conductor that tends to oppose any change of electron flow (current) through the conductor. Inductance reveals itself only when current is varying in the conductor; a back emf (electromotive force) is induced in a direction that tends to oppose the change in current flow. It is apparent that even a very short section of straight wire possesses self-inductance. The conductor does not have to be wire, however; it can be any conductor, any shape or size.

Usually, the actual amount of self-inductance is small, but its effect becomes important at frequencies above 30 MHz. The effect may be desirable or unwanted, but it cannot be ignored. A complex equation is needed to find the actual value of self-inductance, but the important point here is that the value depends directly on the number of lines of flux surrounding the conductor. Self-inductance is highest at the center of any conductor carrying alternating current, and tapers off toward the outside surface. This is the cause of skin effect, explained later.

UNDESIRABLE EFFECTS.–The property of distributed inductance can cause serious RF losses if leads and connecting linkages are not kept as short as possible. Figure 7-1 demonstrates how this loss takes place. The plate tank circuit (A) is designed to operate at a frequency of 4 MHz. The inductor is connected to the tube plate by a wire having a self-inductance of approximately 0.1 microhenry (μh).

Ignoring loading and other factors; calculation shows that the resistive impedance offered by the tank circuit at resonance is 4,710 ohms, where the inductive reactance ($X_L = 2\pi fL$) of the connecting wire is approximately 2 ohms, and is so small in proportion to 4,710 ohms that it can be neglected at this low frequency.

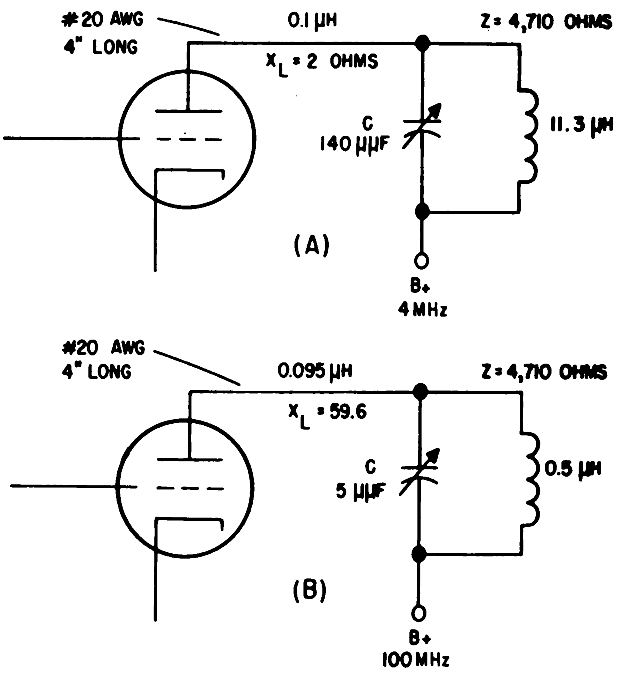

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Figure 7-1.–Effect of distributed inductance at higher frequencies.

When the operating frequency is raised to 100 MHz (fig. 7-1 (B)), the inductance of the tank coil must be reduced to resonate at the higher frequency. At 100 MHz, the self-inductance has decreased slightly but the increase in frequency raises the inductive reactance of the plate lead to 59.6 ohms. The resistive impedance of the tank circuit is still 4,710 ohms at resonance. A voltage divider effect occurs, which prevents the entire RF signal output of the tube from being impressed across the tank circuit and results in a loss of gain. In addition, the introduction of an inductive component causes a phase lag that is undesirable in certain applications. At higher frequencies, the effect becomes even more pronounced, introducing larger losses.

DESIRABLE EFFECTS.–In certain circuits, a condition of series or parallel resonance is desired, and the property of distributed inductance, distributed capacitance, or a combination of both, may be used to achieve this. For example, to provide a bypass for signal voltages from the low-impedance end of an IF tank circuit back to the cathode of the tube, a series resonant circuit offers the lowest impedance path. When the IF frequency is above 30 MHz, it is possible to get the effect of series resonance by cutting the leads of the capacitor to lengths offering the necessary series inductance. This is shown in figure 7-2 (A). Note that the capacitance is lumped, but the inductance is the distributed inductance of the capacitor leads. (See fig. 7-2 (B).) However, the signal voltage sees a certain value of each property, regardless of whether the properties are lumped, distributed, or any combination thereof.

INDUCTIVE COUPLING.—When a conductor carrying alternating current runs sufficiently close to another conductor, its magnetic field induces an electromotive force in the second conductor, causing a current to flow. This is the effect of mutual inductance.

The study of mutual inductance and coupling at lower frequencies usually is restricted to coils and transformers, but above 30 MHz the effect of coupling between two conductors—even two straight pieces of wire—becomes important. This is true because the amount of coupling or mutual reactance between two inductors increases as the frequency is increased, if the physical relationship remains the same.

Some effects of coupling between distributed inductances are undesirable. For instance, if the grid and plate leads of a single-tube amplifier stage are permitted to run close to each other, signal energy from the plate circuit may be coupled back to the grid, causing either regeneration or degeneration. Distributed capacitance also is present, but only the inductive coupling effect is considered at this time. As another example, a current carrying wire may be too near a tube shield, inducing an emf that causes current to flow in the shield. This current flow through the shield is a power loss that can be supplied only from the current carrying wire.

When inductive coupling causes circuit imbalance or power loss, it usually is spoken of as stray coupling. The amount or degree of coupling depends directly on the relative positions of the conductors as well as their distance from each other. Figure 7-3 shows the effect of physical position on the degree of coupling. In (A) the coupling is loose, inasmuch as the leads are crossing at right angles, and the least mutual inductance results. The coupling between the wires (B) and (C) increases because of the greater amount of mutual inductance. Practical circuits are laid out with the shortest possible leads, well separated from one another in distance from the chassis and shields. If two wires must cross, they should cross at right angles, because in this manner the smallest mutual inductance results.

Distributed Capacitance

The term "distributed capacitance" refers to the capacitance between any point on a conductor and all surrounding objects. Capacitance exists between any two points that are at different electrical potentials. This is true whether the points of different potential are in different conductors or in the same conductor. Although the self-capacitance of a conductor is of relatively little importance, except in special circuits, the effect of the capacitance between two conductors must be taken into consideration at VHF/UHF/microwave frequencies. This is because of the distributed capacitance that exists between the parts of circuit elements and the electrodes of electron tubes, as well as between leads and switch contacts.

The actual value of distributed capacitance changes only slightly with frequency, but the reactance changes greatly. The formula for capacitive reactance ($X_C = \frac{1}{2\pi fC}$) shows that, if the value of capacitance remains the same, increasing the frequency causes the capacitive reactance to decrease. Therefore, a small value of distributed capacitance at the lower frequencies offers a high reactance to the flow of a.c., but at higher frequencies it offers a lower reactance. This effect often is undesirable when it occurs accidentally between two conductors in a circuit, but may be used deliberately to achieve series or parallel resonance in resonant line sections. The losses in distributed capacitance are lower than those in lumped capacitors because the dielectric is usually air, instead of a solid, and because the RF resistance and distributed inductance values are smaller.

UNDESIRABLE EFFECTS.—An example of the manner in which distributed capacitance may upset the proper operation of a circuit is shown in figure 7-4.

Assume that C_d represents a distributed, or stray, capacitance of $1\mu\mu f$ appearing between ground and the lead from the coupling capacitor to the grid of tube V2. The stray capacitance C_d effectively shunts the 5,000-ohm grid impedance Z_g. If an RF signal at a frequency of 2 MHz is traveling from the tank circuit of V1 to the grid of V2, the $1\mu\mu f$ distributed capacitance

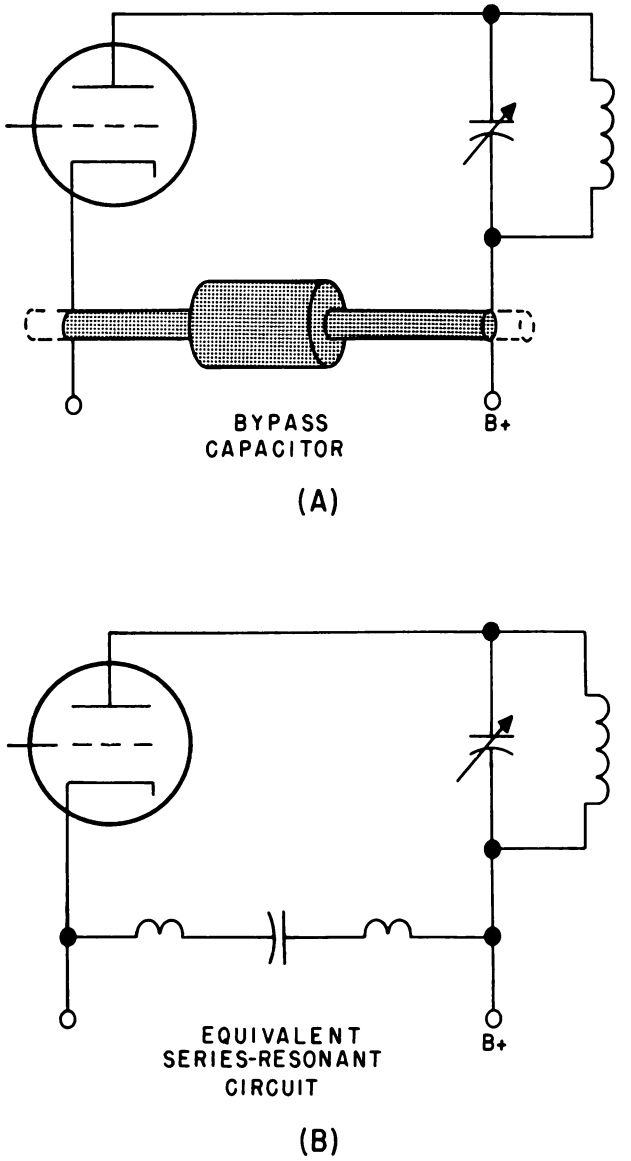

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Figure 7-2.–Series resonance; lumped capacitance and distributed inductance.

offers a capacitive reactance of 79,618 ohms to the signal. This value is so high in relation to Z_g that its effect is negligible at this frequency and similar low frequencies. If, however, a 100 MHz signal voltage is coming from the tank circuit of V1, the same 1-$\mu\mu$f stray capacitance offers only 1,592 ohms of capacitive reactance.

Now the signal voltage sees a relatively low impedance path across the stray capacitance, offering less than one-third the opposition of the grid impedance Z_g. Therefore, more than two-thirds of the signal voltage is shunted across this path and lost. If the frequency of the signal voltage is increased to 400 MHz the reactance drops to 398 ohms, and only a very small amount of the signal voltage reaches the grid impedance.

To keep the stray capacitance at a minimum, the circuit wiring is kept well spaced with short leads that run at right angles to one another whenever possible.

DESIRABLE EFFECTS.–For certain applications, such as IF amplification, a parallel LC (inductance-capacitance) circuit, resonant at a single frequency, is useful. A simple way of achieving this is to wind a coil in such a manner that the total distributed capacitance is used to make the coil self-resonant at the desired frequency.

Part (A) of figure 7-5 shows the distributed capacitance that exists because of the difference of potential between adjacent turns of any coil. The sum of these small values is shown in part (B) as an effective value of capacitance in parallel with the lumped inductance of the coil. Although most inductors are wound to minimize the distributed capacitance, some are designed to offer the necessary capacitance to provide a desired L/C ratio. This offers an advantage because the response of the tuned circuit can be made sharper than would be possible with lumped-property coils and capacitors.

Distributed Resistance

The term "distributed resistance" seldom is used, because it is necessary to distinguish between the resistance offered to d. c. and low-frequency a. c. and the resistance offered to RF currents at the higher frequencies.

Depending on the conductivity of the metal or alloy, all conductors have d-c resistance. It is distributed uniformly along conductors that are uniform in cross sectional area, shape, and conductivity. Resistance to RF, however, is caused by d-c resistance plus the effect of self-inductance, which is greater at the center of a conductor than at the surface. At the lower frequencies, this self-inductance has little effect on the flow of current because the values of inductive reactance are extremely small. As the operating frequency increases, the

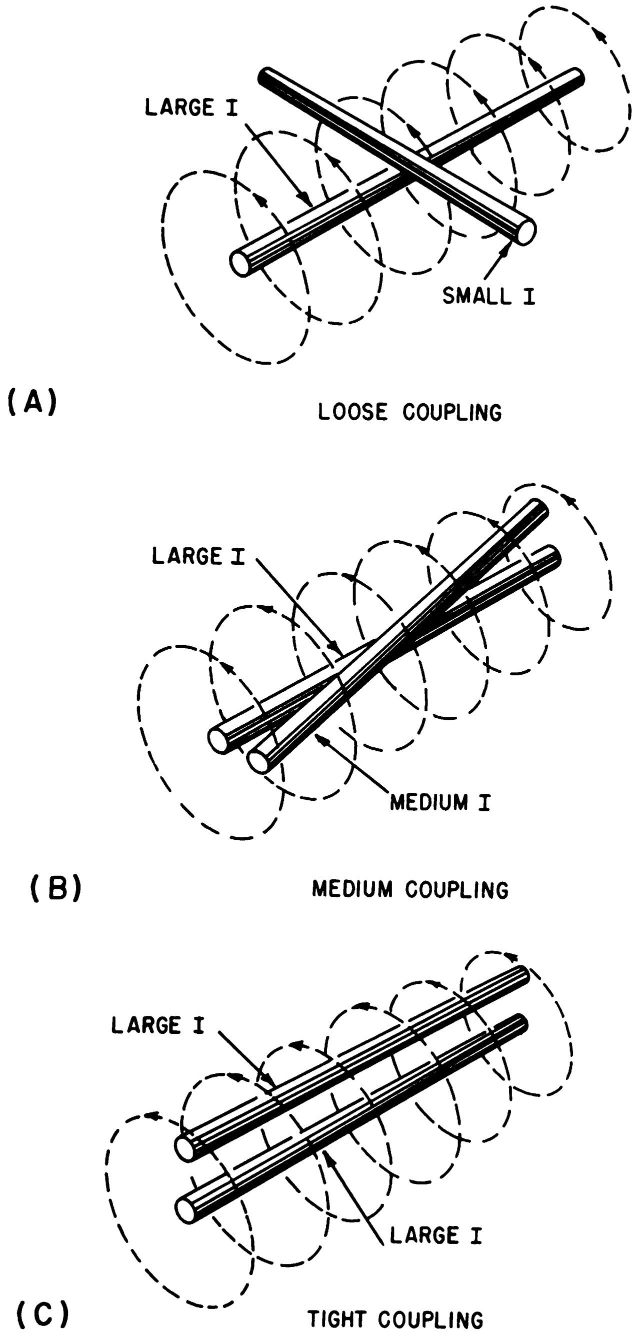

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Figure 7-3.—Inductive coupling effects at higher frequencies.

inductive reactance at the center of the conductor becomes higher, and the current seeks the lower reactance path toward the surface, resulting in a current distribution that is not uniform.

This tendency of the current to flow on or near the surface of a conductor is called SKIN EFFECT. As the frequency increases, less current flows in the center of the conductor and more flows on the surface. The result is that more current is forced through less conductor material, with higher losses and more heating. Because the center of the conductor is not carrying current, the effect is the same as using a smaller conductor. The RF resistance at higher frequencies can amount to several times the d-c resistance of the same conductor.

MINIMIZING SKIN EFFECT.—Skin effect takes place regardless of the shape of the conductor, but it causes less RF resistance in conductors having rectangular cross sections than in those that are circular. Flat copper strips are sometimes used, but are more expensive and not easy to work.

Litz wire, as it commonly is called, is made up of many strands of very fine enameled wire woven together. The current is divided among the strands, and the skin effect on any single conductor is extremely small. Litz wire is comparatively expensive, however, and is not widely used.

Probably the best method of avoiding losses from RF resistance is by silver plating the conductors. This does not eliminate skin effect,

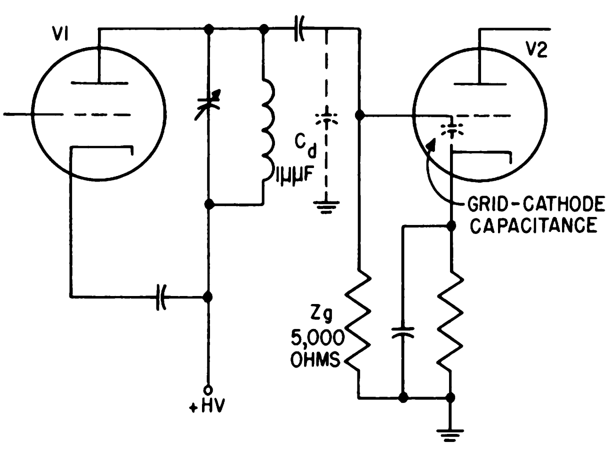

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Figure 7-4.—Effect of distributed capacitance at higher frequencies.

but takes advantage of it. When the plated conductor carries RF current, skin effect takes place as usual. Now, however, the current is flowing in the silver plating, which has less d-c resistance than ordinary conductors; therefore, the RF resistance is reduced considerably. In practice, plating is expensive, limiting its use.

The most common means of reducing RF resistance is to use a hollow conductor or one of larger diameter. Again, this does not eliminate skin effect. The depth to which the current penetrates is affected only by the frequency and the conductor material; consequently, when the diameter is increased, the current layer has the same thickness but more cross sectional area in which to flow. This reduces the effective RF resistance.

LUMPED-PROPERTY COMPONENTS

A lumped-property component is an electronic part in which a definite amount of capacitance, inductance, or resistance exists, usually with relatively little of either of the other properties present. Capacitors, coils, and resistors used in radio equipment operating at frequencies below 30 MHz generally are lumped-property components.

As the frequency of operation is raised, the electrical loss in lumped-property components increases, until a frequency is reached where this increasing loss cannot be tolerated. The increased loss is actually a combination of three distinct effects–dielectric loss, RF resistance loss, and radiation loss.

Loss in even the best dielectric materials increases with frequency, because a definite amount of applied electrical energy is lost in each cycle, and the more cycles that occur in a unit of time, the more heat is generated in the dielectric.

The RF resistance loss also increases with increasing frequency, because of skin effect.

Radiation loss occurs in any RF circuit because of direct radiation from the parts. This loss is usually negligible, so long as the circuit is not more than about one-tenth of a wavelength in any physical dimension. With increasing frequency, however, it becomes impossible to scale the components down in physical size in proportion to the decreasing wavelength, and radiation losses increase. The addition of RF shielding around the circuit also causes energy to be lost in heating the shield, rather than by radiation.

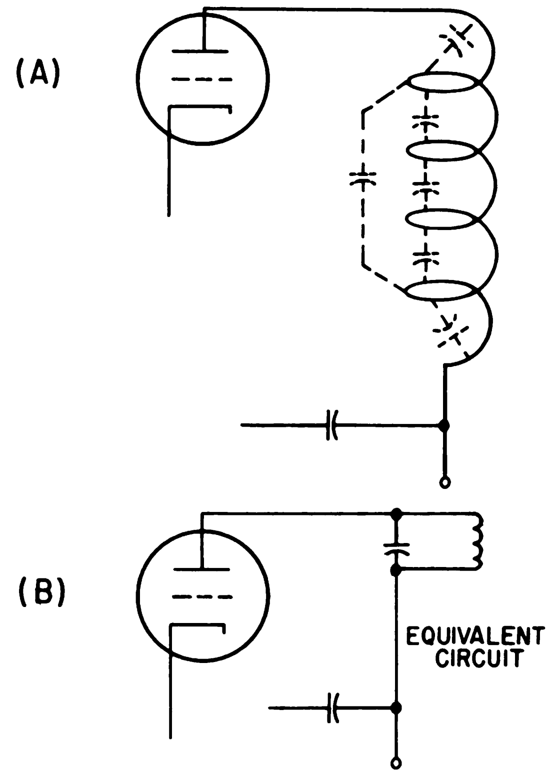

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Figure 7-5.–Parallel resonance; lumped inductance and distributed capacitance.

Capacitors

All capacitors, of any size, type, or construction, have characteristics that cause them to behave in a way unlike the theoretical ideal capacitor, which would have pure capacitance, and no inductance or resistance. Practical capacitors actually have some series inductance because of their leads and internal metallic foil plates. This inductance is effectively in series with the actual capacitance as shown in the approximate equivalent circuit of figure 7-6 (A) where C represents the actual capacitance, L the inductance of each lead, and R the effective RF series resistance of the leads and foils. Losses in the dielectric are represented by the shunt conductance, G. Below 10 MHz, dielectric losses are seldom serious, even in ordinary paper capacitors, and in high quality mica and ceramic units it has no serious effects at the highest frequencies.

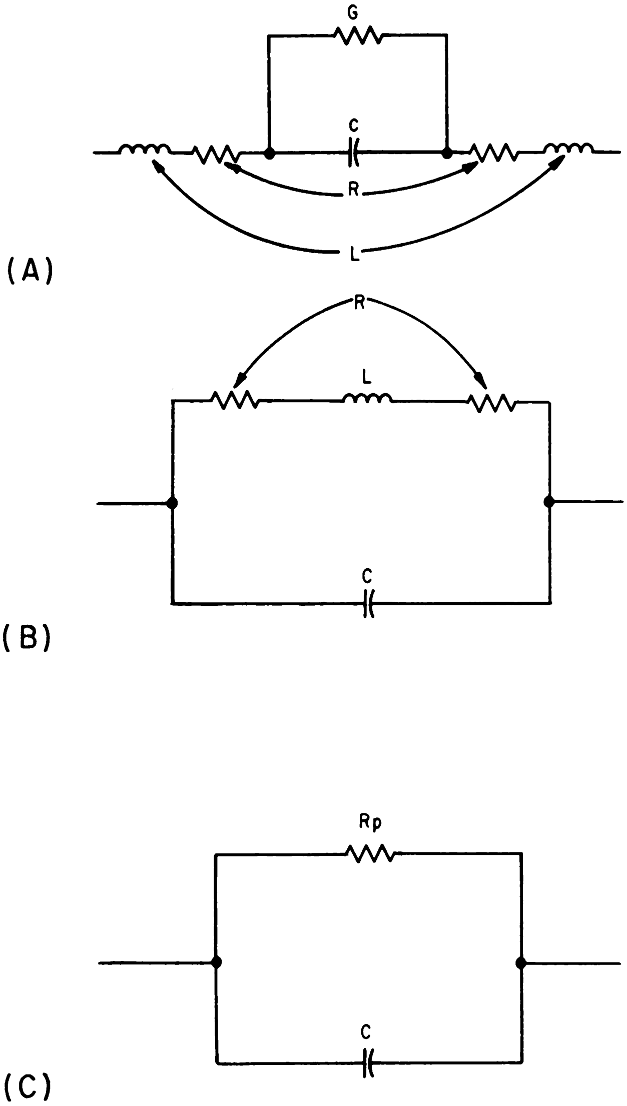

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Figure 7-6.—Equivalent high frequency circuits.

Since capacitors have a small (but significant) amount of inductance in series with the actual capacitance, there is a resonant frequency at which the reactances of the inductance and capacitance become equal, and cancel each other. The reactance becomes capacitive below series resonance, and grows larger as the frequency decreases. The opposite effect takes place above resonance, where the reactance is inductive, and grows larger with increasing frequency.

The common types of electrolytic, mica, paper, and ceramic capacitors are subject to increasing losses as the operating frequency is increased. In electrolytic capacitors, these losses and the inductance of the leads and internal foil strips that form the plates make them practically ineffective as capacitors at frequencies above a few megahertz. Even in equipment operating below 30 MHz, electrolytic capacitors usually are shunted with a paper or mica capacitor of suitable value, which bypasses the higher frequency currents around the electrolytic unit.

Paper capacitors also are subject to serious losses as the frequency is raised, but not to the same severe extent as in electrolytic units. The series inductance of paper units is large, and causes them to become series-resonant at frequencies ranging from 1 to 10 MHz, depending on the capacitance and lead length.

Mica capacitors, because of their lower losses and smaller series inductance, have an extended range of usefulness. Average types become series-resonant at frequencies from 10 to 100 MHz, depending on the capacitance value and lead length.

Ceramic capacitors are a more recent development and have improved properties in certain respects. Their losses are lower than those of mica units, and their design permits a much lower series inductance. As a result, their series resonance may be as high as 400 or 500 MHz and this, together with their stability and low losses, makes them preferred in many VHF/UHF/microwave applications.

IMPROVEMENTS IN CAPACITORS.—Changes in the materials and design of capacitors have been made to adapt them for more effective performance at frequencies above 30 MHz. In general, since capacitors do not behave as capacitors above their own resonant frequency, most of the improvements have been made with a view to raising the resonant frequency. The greatest improvement resulted from the development of ceramic materials that made possible ceramic-dielectric capacitors with only two plates, as compared with the many interleaved foils necessary in paper and mica units. Ceramics also made possible capacitors with various temperature coefficients which can be used to improve the stability of critical circuits.

Various ceramic materials, such as barium and strontium titanates, have been found to have high dielectric constants and good dielectric strength. By plating or firing silver electrodes directly on thin plates of this dielectric material, air and moisture are prevented from getting between the plates of the capacitor. This results in greatly improved stability. By varying the mixture of the ceramics, the temperature coefficient of the capacitor can be made negative, zero, or positive, as desired. Ceramic capacitors then can be used to compensate for frequency drift caused by changes in other components with changes in temperature. Skin effect is reduced by using short, heavy leads, and losses caused by surface leakage and humidity are minimized by sealing the surface with baked silicon lacquer. A similar process of plating or coating the silver electrode on mica also has been developed for the manufacture of mica capacitors, with considerable improvement in their stability and high-frequency performance.

Inductors

All inductors have some distributed capacitance between turns, which appears as a small capacitance in parallel with the external circuit. When the applied frequency is increased to a point where the distributed capacitance of the coil resonates with the inductance, a new effect appears. The coil becomes a parallel-resonant circuit (fig. 7-6 (B)) to the external circuit connected to its terminals. The resistance in this equivalent circuit represents the losses incurred in practical coils. This self-resonant characteristic is used in many applications in VHF/UHF/microwave receivers. The inductor is made to resonate with its own self-capacitance, plus the tube input and stray circuit capacitance. This eliminates the need for a separate tuning capacitor and provides the highest possible inductance-capacitance ratio, the largest load impedance, and the greatest stage gain.

Self-resonant inductors are often used in the IF amplifiers of communications receivers. If adjustable tuning is required, it is accomplished by varying the inductance either by a switching arrangement or with an adjustable core (slug) of plastic impregnated with iron powder.

In transmitter circuits, the inductor must handle considerable power without serious heating. This requires a coil of larger physical size, and usually makes the use of iron powder cores impractical because such cores tend to saturate magnetically and lose efficiency as the power level increases. Inductors in transmitter circuits thus are usually of the air wound, self-supporting type.

Resistors

The effects of increasing frequency on the performance of some types of resistors are such that the resistors cannot be used efficiently at frequencies of 30 MHz and upward. Wire wound resistors that are used at low frequencies become useless above this range because of unavoidable inductance and capacitance, which introduce unwanted reactive or resonant effects. Therefore, composition resistors made of finely divided carbon in a suitable binder are most commonly used in this frequency range.

For practical purposes, the simple equivalent circuit shown in figure 7-6 (C) illustrates the effective impedance of a composition resistor at high frequencies. This equivalent circuit generally is used in the design of VHF, UHF, and microwave circuits. R_p is the reciprocal of the conductance and is referred to as the parallel resistance. The total effective capacitance, C, is caused by the capacitance between the leads and the distributed capacitance.

Resistors made by depositing a thin layer of pure, finely divided carbon or a carbon and boron mixture on the surface of a ceramic or glass tube provide improved performance characteristics at all frequencies. They are particularly stable, and they show less change in impedance with increasing frequency.

FREQUENCY LIMITATIONS OF CONVENTIONAL OSCILLATORS

The principal factors which limit the frequency of the ordinary type oscillator are the construction of the tube and the external circuits which connect to the tube.

Although the basic principles of vacuum tube operation are unchanged, certain factors that can be disregarded in tube operation below 30 MHz become important at higher frequencies. The inductances of the electrode leads and the capacitances between electrodes are very small, but at higher frequencies their reactances become significant. In addition, electrons do not travel instantaneously from the cathode to the plate, but require a TRANSIT TIME. This causes an in-phase grid current to flow, even though the grid is negative, and results in a loading effect across the input that reduces overall gain in all classes of tube operation.

Skin effect in the electrodes and electrode leads causes the RF resistance to increase with frequency. Dielectric losses in the insulating electrode supports are increased, and some power is lost by direct radiation from the electrodes and their leads. The effect of these factors is to cause tube efficiency to become progressively lower as the operating frequency is increased. For example, a tube operated as an amplifier at 50 MHz gives less output for a given signal input than at 5 MHz, even if the external circuits are equally efficient at both frequencies. Also, because these losses increase with frequency, there is a practical upper frequency limit beyond which the tube is not useful as an amplifier. If the same tube is operated as an oscillator, the high frequency limit of operation will be about two-thirds to three-fourths that of the limit as an amplifier, because the tube no longer can supply sufficient output to make up the increased losses and still provides a useful output signal.

These effects are always present in a vacuum tube; no matter what the operating frequency. As the frequency is raised, the effects increase and become so large that they place an effective upper limit on useful operation. Although it is not necessary to learn new operating principles, it is important to understand how and why these characteristics that previously were disregarded become major limitations at frequencies above 30 MHz.

TUBE CONSTRUCTION FACTORS

As the wavelength is made shorter, it becomes comparable in length to the physical length and spacing of tube electrodes and leads. The apparent solution to this difficulty is to scale down the entire tube structure. There is a practical limit, however, governed by the power handling capacity required. New tube designs have been developed that successfully overcome one or more of the limitations without requiring a drastic size reduction. For further details on tube design, review chapter 7, Vol.1I, of Basic Electronics, NavPers 10087-C.

Interelectrode Capacitances

As has been pointed out in Basic Electronics, NavPers 10087-C, a small but significant value of capacitance must exist between any element of an electron tube and each of the other elements. Additional capacitances exist between the leads, particularly in those tubes in which the leads are brought out through a common stem to the base. When the tube is operating with normal voltages applied, the effective capacitances between electrodes are different from the capacitances when the cathode is not emitting. These differences are caused partly by expansion of the parts when the tube heats and partly by the electron stream.

When the tube is cold, the dielectric between electrodes is mostly vacuum, but in operation this vacuum is partially filled with a stream of electrons, resulting in a change in the dielectric constant. Naturally, this changes with variations in the electron stream. The normal capacitance values are measurable, and are listed in tube characteristics tables.

The discussion of interelectrode capacitance in Basic Electronics, NavPers 10087-C, establishes the relationship between operating frequency and capacitive reactance within electron tubes. A good point to remember is that the higher the frequency (or the larger the interelectrode capacitance) the higher the current flow through this capacitance. In most UHF oscillators employing ordinary tubes, interelectrode capacitance currents are much greater than the power currents supplied by the tube. These higher currents cause power losses in the resistance in the oscillatory circuit.

Since interelectrode capacitances are effectively in parallel with the tuned circuit, they affect the frequency at which the tuned circuit resonates. In the circuit illustrated in figure 7-7, the plate to cathode capacitance is in parallel with the series combination of the plate to grid capacitance and the grid to cathode capacitance. All these capacitances together form a part of the total capacitance of the plate's tuned circuit. Their total capacitance is calculated by the formula,

$$C_t = C + C_{pk} + \frac{C_{gk} \; C_{gp}}{C_{gk} + C_{gp}}$$

Not only does interelectrode capacitance limit the frequency by establishing a minimum value below which it is impossible to go, but it also varies with the applied voltages and with the loading of the oscillator. This causes frequency instability, particularly when the interelectrode capacitance forms a large part of the tuning capacitance.

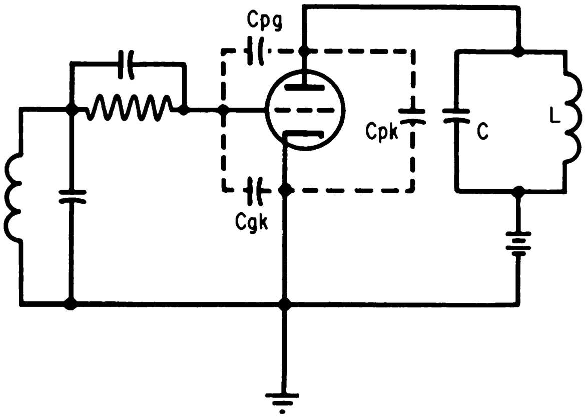

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Figure 7-7.—Effect of interelectrode capacitance on frequency of tuned plate, tuned grid oscillator.

Inductance of Leads

Another frequency limiting factor is the inductance of the lead to each tube element. Because any conductor possesses self-inductance, the internal leads to the tube elements and the elements themselves, as well as the tube pins, have some inductance. For example, within a tube operating above 30 MHz, circuit calculations must take into consideration the effective values of inductance. This inductance is in series with the plate, grid, and cathode, and although the actual inductance of a lead is usually small, the reactance offered at frequencies of several hundred megahertz becomes appreciable.

While these inductances do not necessarily impair the efficiency of the oscillator, they may represent a major portion of the inductance of the tuned circuit and limit the frequency by setting a minimum limit on the inductance. Furthermore, since the cathode lead is frequently common to both plate and grid circuits, feedback may take place through it and produce an additional loss of efficiency.

Transit Time

The effect of transit time is of special concern in connection with the input impedance of the tube. The signal applied to the grid causes a flow of electrons past the control grid, which in turn causes a current to be induced into the grid. This induced grid current may flow either into or out of the grid, depending on the relative grid voltage at the time. Part of the current flowing in the grid is the current which charges the grid to plate capacitance (C_{pg}, fig. 7-7). The voltage which produces this current is the vector sum of the input voltage (grid to cathode) and the output voltage (across the plate load).

Grid current flow absorbs power from the input signal, even though the grid is always negative, and has the same effect as if a shunt resistance and a shunt capacitance were connected across the grid and cathode terminals of the tube. The loss of signal energy brought about in this manner is the most important effect of transit time, and the loss increases as the frequency increases.

At lower frequencies with a resistive load, the input and output voltages are (for practical purposes) 180° out of phase and add algebraically to determine the charging current for the grid to plate capacitor. This current is 90° out of phase with the input voltage. However, at higher frequencies where transit time is an important factor, the plate current lags appreciably behind the input voltage. At these frequencies, the plate voltage is less than 180° out of phase with the input voltage, and the voltage across the capacitor lags the input voltage slightly. As a result, the charging current is no longer 90° out of phase, but now has an in-phase component. The in-phase current results in power being consumed in the grid circuit. The consumption of power is effectively the same as adding a high resistance between the grid and cathode, with the resistance decreasing as the frequency is increased.

REDUCING TRANSIT TIME EFFECTS.—Transit time effects can be minimized by scaling down tube dimensions and increasing operating voltages. Miniaturization is utilized widely. Amplifiers designed for use above 30 MHz usually have close interelectrode spacing. Many transmitting tube types are very small in proportion to their power ratings, and require cooling by forced air draft.

Where close spacing is utilized, the distance from the cathode to grid is particularly important. Preventing the electrons from leaking from cathode to plate around the ends of the control grid supports is important, because such leakage would result in increased transit times.

Screen grid tube types have naturally shorter transit times than triodes, and are used in many VHF/UHF/microwave equipments to reduce transit time effects.

Miscellaneous Effects

Other effects on electron tubes at the higher frequencies are caused by grid gas current, grid emission, and heat radiation.

In any electron tube there are always some molecules of gas, because it is impossible to produce a perfect vacuum. When electrons collide with these molecules, positive ions are created and are attracted to the negative control grid. This causes a grid current to flow when the grid is negative. The grid current thus produced is small but has the effect of making the grid less negative, which is undesirable in view of the effects of input resistance in this frequency range.

Any metal emits electrons if heated sufficiently, although some are much more efficient in this respect than others. In miniature tubes suitable for use at frequencies higher than 30 MHz, the grid is subjected to heating by the nearness of the cathode as well as by the in-phase grid currents. Some electrons strike the grid even though it is negative, causing the possibility of secondary emission. As a result, there is a possibility of both primary and secondary emission from the grid. This adds to the space charge and is undesirable because it varies erratically. The effect can be reduced by plating the grid with a metal that does not emit electrons easily. Gold is particularly effective and is used where the type of operation is critical enough to warrant the expense. Another method, somewhat less effective, is spraying the grid with finely powdered boron carbide.

The radiation of heat from the plates of air-cooled tubes becomes a factor of importance because the tube efficiency is reduced as the frequency is raised. For a given power input, a reduction of efficiency causes higher plate dissipation. This means that the input power must be reduced to keep the plate dissipation from going above the rated value and causing serious overheating. When the input power is decreased, however, the useful output power drops.

The most common method of improving the thermal radiation of the tube plate consists of coating the plate with finely divided carbon. The resultant dull black surface is about 60 percent more efficient as a heat radiator than polished metal.

Overcoming Tube Limitations

There are several ways to reduce the effect of interelectrode capacitances in vacuum tubes, though none is completely satisfactory. One is to move the electrodes farther apart; however, this is not desirable because it increases the transit time. Another method is to reduce the size of the tube and electrodes; this is satisfactory except for one ill effect. It decreases the power handling ability of the tube, varying directly with the square of the factor by which the electrodes are reduced. Another method is to separate the leads and to bring them out of the envelope at the point nearest the electrode; this results in a slight decrease in the capacitances.

Similarly there are several ways to reduce the inductances of the leads. Bringing out electrode leads through the envelope at the nearest point decreases the inductances of the leads as well as the capacitances. Another method is to make double connections to the electrode. This makes two parallel inductances, thus cutting the lead inductance in half. Another method is to arrange the leads as extensions of the external transmission lines which are the resonant elements of the circuit. Thus the interelectrode capacitances and lead inductances are incorporated as part of the tuned circuit. (See fig. 7-8.)

It is possible to minimize the inefficiency previously mentioned by using a tube that has two separate external cathode connections. When one cathode lead is used for the grid return and the other for the plate circuit, the unwanted feedback is prevented since the grid and plate currents do not flow in a common lead inductance.

For reducing transit time, closer spacing of the electrodes may be employed. Closer spacing of electrodes, however, causes higher interelectrode capacitances. Therefore, it can be used only when the electrodes are made smaller.

Transit time may also be reduced by the use of higher plate voltages. For this reason UHF oscillators operate at very high plate voltage. The fact that a radar and other pulsed transmitters do not operate continuously is an advantage in that high enough voltages may be used to reduce transit time without exceeding the maximum power rating of the tube. Operating with high voltages does, however, necessitate

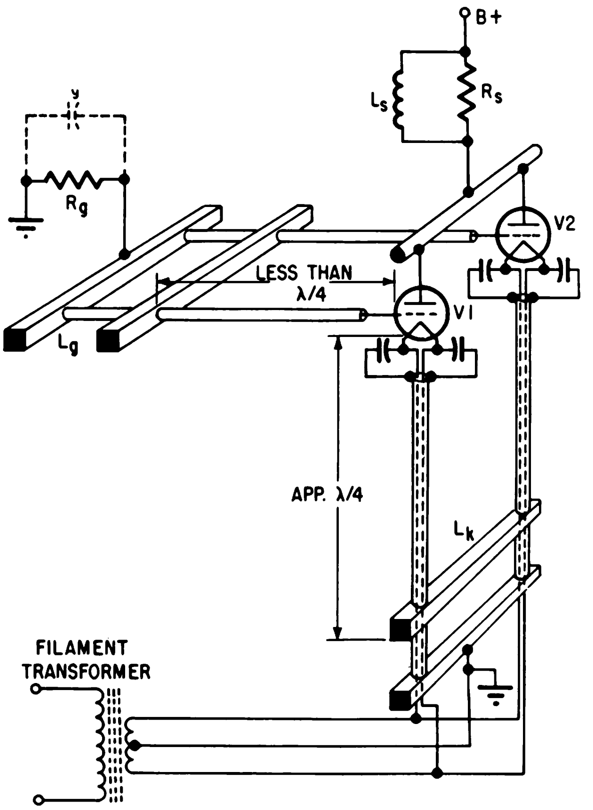

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Figure 7-8.—Tuned grid, tuned cathode oscillator.

some precautionary measures (such as separating the leads to avoid the presence of excessive voltage gradients in or on the surface of the glass envelope, and avoiding sharp projections on the high voltage leads or electrodes to prevent arcing).

LIMITATIONS DUE TO EXTERNAL CIRCUITS

In addition to the limitations placed on the operating frequencies of oscillators by the tubes themselves, additional limitations are imposed by the external circuits. An increase in frequency causes a rather rapid increase in power losses in the external oscillatory (tank) circuit. These losses are due, primarily, to the skin effect of current in conductors, and to radiation from the conductors.

Skin Effect

Skin effect causes a considerable increase in the resistance in an electron tube circuit. This results in a lower Q and increased I^2R losses. To prevent skin effect losses, conductors are made large in size and tubular in shape since current flows only in the surface at and above UHF frequencies. In addition they may be plated with silver, since it has a higher conductivity than copper. At microwave frequencies current flow will be in the silver plating.

Radiation

Radiation, the other cause of power loss, is due to incomplete cancellation of electromagnetic fields in the region surrounding the circuit. When the frequency is low enough so that the spacing between two parallel conductors equals only a very small fraction of a half wavelength, there is almost complete cancellation of fields in all directions. At higher frequencies, however, the same spacing would represent a larger fraction of a half wavelength. This means less cancellation. In extreme cases (for example, where the spacing is a half wavelength) the fields add in the direction of the plane containing the two conductors. This causes the tuned circuit to radiate energy like an antenna. Therefore, as the frequency increases, it is necessary to reduce the spacing between the parallel elements. However, there is a limit; too close spacing will result in arcing of the tank circuit. Another means of eliminating radiation is the use of concentric lines instead of open wire line. This eliminates radiation entirely, since the outer conductor acts as a shield which prevents the electromagnetic field from expanding into space.

Limits of Inductance and Capacitance

At UHF frequencies and above, it is necessary that the inductances and capacitances in the oscillatory circuit be very small. The lower limit of capacitance is the sum of the interelectrode capacitances and the distributed capacitance of the leads. The lower limit of inductance is the lead inductance plus the inductance necessary to connect the tube electrodes externally. UHF oscillators approach both these limits; the only capacitance in the tank circuit often is a small trimmer capacitor for fine tuning adjustments, and the inductance often is the shortcircuited transmission line less than one-quarter wavelength long. (See fig. 7-9.)

To obtain smaller values of inductance, the length of the line is decreased. Frequently the tank circuit is located near a flat surface and parallel to it. The flat surface acts as a shield and, while it does not affect the electrical length of the line, it does lower the characteristic resistance of the line.

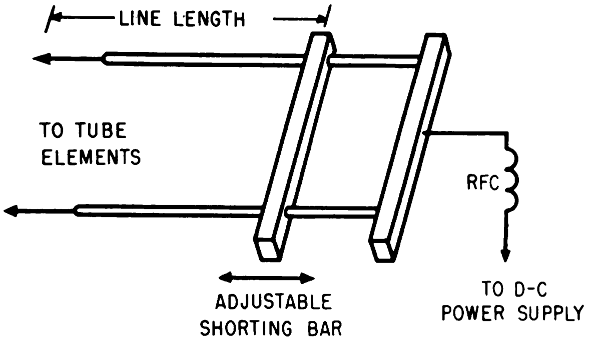

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Figure 7-9.–Parallel wire resonant circuit.

At microwave frequencies, even the small amounts of inductance and capacitance mentioned above prove to be excessive, so that at microwave frequencies the resonant cavity is almost exclusively used as the oscillatory circuit.

LIMITATIONS IN TRANSISTORS

The same factors which impose high-frequency limitations on tubes also affect transistors. In addition, it is difficult to find parameters which accurately describe the performance of those transistors that are capable of being used at UHF and microwave frequencies.

The capacitance between electrodes is one factor in determining high-frequency response. Interelectrode capacitances also depend on the width of the depletion layers at the junction, and this width depends on bias. The interelectrode capacitances in tubes are not as bias dependent. Because transistors are smaller, the electrode leads are shorter and this factor helps reduce the lead inductance. The effect of transit time is similar to that in tubes, although the operation is different. The slower velocities of the current carriers are counterbalanced by the shorter distances traveled in transistors, but the maximum frequencies attainable are the same as in tubes.

LIGHTHOUSE TUBE OSCILLATOR

The lighthouse tube oscillator is a single tube oscillator used in test equipment and low power transmitters. The lighthouse tube, which gets its name from its peculiar construction, will operate at frequencies as high as 4,000 MHz. Its plate, grid, and cathode connections are arranged so that it may be mounted directly in the tuning assembly. (See fig. 7-10.) The component called the tuner consists of three coaxial cylindrical conductors, of which the inner cylinder makes contact with the plate, the next with the grid, and the outer conductor with the shell of the tube.

The outer conductor provides an RF connection to the cathode through capacitance. The space between the cathode and grid conductors forms a coaxial cathode line which in turn is shorted by means of a plunger. The insulation at the tube base between the cathode and the cathode shell (or external connection) is the dielectric between the rings which form the cathode capacitive coupling. If this capacitive coupling were not used, the grid would have a d-c path from its cylinder through the plunger and the cathode cylinder to the cathode. This capacitance in the tube base is great enough to form a virtual short circuit for RF. The d-c grid to cathode path consisting of R_g and C_g forms the grid leak bias circuit.

In the plate circuit, the plate line consists of the grid and plate conductors. It is open circuited at the end away from the tube. The plate voltage is applied to the plate lead through the plate tuning rod at the point where the plate line is shorted. This point is one-quarter wavelength from the end. This quarter-wave section (which is shorted at the point where B-plus is applied) presents a high impedance to FG from the open ended plate line, and therefore prevents RF from flowing into the power supply.

EQUIVALENT CIRCUITS

The equivalent circuits in figure 7-11 show the evolution of the lighthouse tube oscillator.

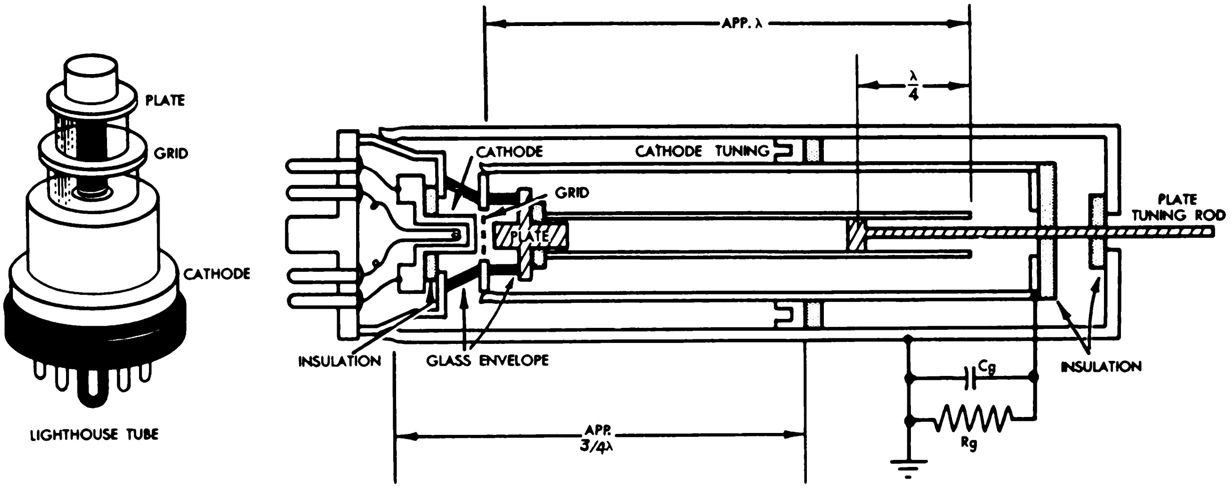

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Figure 7-10.—Lighthouse tube oscillator.

In (A), the components L_k and L_p represent the inductances of the shorted cathode line and the open circuited plate line respectively. This is a true representation of the actual circuit provided that the cathode line is less than three-quarters of a wavelength long and provided that the plate line is less than a full wavelength long. (The three-quarter wavelength and full wavelength were chosen for this circuit rather than the one-quarter and one-half wavelength due to the fact that at the frequency of operation the latter fractions of a wavelength are inconveniently short.) However, keep in mind that if the cathode line is slightly less than one-quarter wavelength, it acts like an inductance; and if the plate line is slightly less than one-half wavelength, it acts like an inductance. There is no lead inductance shown in the circuit since the lines connect directly to the electrodes. The interelectrode capacitances complete the equivalent circuit.

In (B), the parallel combination of L_p and Cgp are represented by X2 and the parallel combination of L_k and C_{gk} by X1. Obviously the reactances X2 and X1 along with C_{pk}, which can be considered as unknown reactances, must form a resonant circuit. The reactance X1 forms a voltage divider circuit along with C_{pk}. Since the voltage across X1 is the voltage fed back to the grid, it must be 180° out of phase with the plate voltage (which can happen only if X1 is a capacitive reactance). This condition leads to the third equivalent circuit, (C), in which the reactance X1 is represented by a capacitor.

An oscillatory circuit requires at least one inductance; therefore X2 must be an inductive reactance. Hence, in (C), the reactance X2 is shown as the inductance L. This circuit is representative of the oscillator circuit only at the resonant frequency. On examining this circuit, notice that basically it is that of a Colpitts oscillator. If X1 is capacitive, Cgk must conduct more heavily that L_k; therefore the oscillator frequency must be above the resonant frequency of L_k and C_{gk}. Likewise, for X2 to be inductive the oscillator frequency must be below the resonant frequency of L_p and C_{gp}. Thus the oscillator frequency is between the resonant frequencies of the plate circuit and the cathode circuit.

FEEDBACK

In this oscillator, the amount of feedback depends upon the size of C (fig. 7-11 (C)) in relation to C_{pk}. This is a function of the tuning of the cathode line; the cathode tuning serves principally to control the amount of feedback. If feedback is too small, oscillations are weak and may cease completely; if feedback is too

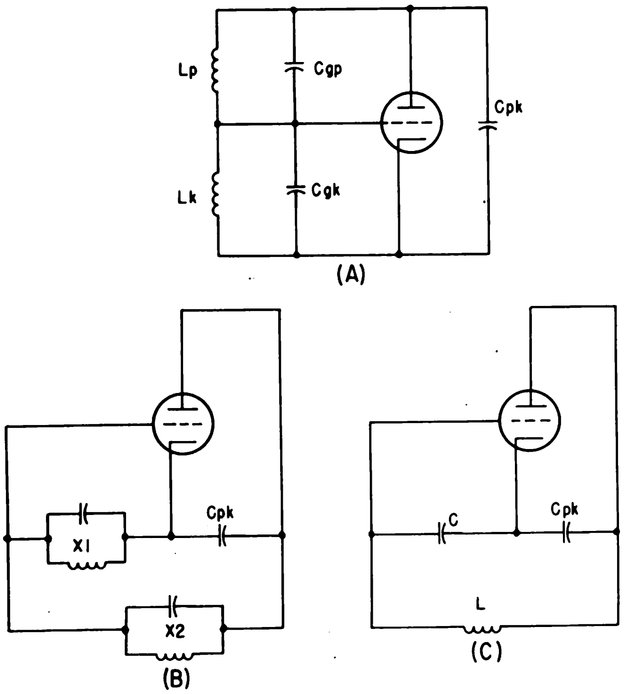

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Figure 7-11.—Evolution of equivalent circuit of lighthouse tube oscillator.

great, power consumption in the grid circuit becomes too large. This results in a decrease in output of the oscillator. The value of C (hence of the cathode tuning) has some effect on the frequency of oscillations, but since C and Cpk are in series, and C is usually much larger than Cpk, C must be changed considerably to appreciably affect the frequency.

TUNING

Since the tuning of the plate line determines the resonant frequency of the plate circuit, which in turn determines the amount of inductance represented by the plate circuit at the oscillator frequency, the plate tuning is the chief control of the oscillator frequency. It has a secondary effect of feedback since C is determined by the relative frequencies of the cathode circuit and of the oscillator. Thus the plate line is tuned to give the correct frequency and the cathode line to adjust feedback for maximum output from the oscillator; but, since there is some interaction, it will be necessary to readjust each line for maximum accuracy.

TRAVELING WAVE TUBE

The traveling wave tube (TWT) is not a new device. It was invented during the latter part of World War II, but due to the instability of the earlier models, it saw no practical use at that time, although its remarkable capabilities and some of its potential applications were well known. The Navy retained an interest in the device because of its potential applications in the fields of communications, radar, and electronic warfare (EW).

Development of the early radars was rapidly followed by the development of techniques to deceive and jam them. The evolution of radar has been partially the result of a continuing need to stay ahead of any new countermeasure tactics which might compromise the radar's effectiveness.

The trend in search radars has been toward higher power and toward electronic counter-countermeasures (ECCM) techniques that will increase visibility despite jamming. A good antijamming radar must be able to shift frequency quickly (and, if possible, over a wide bandwidth) to avoid the jammer's frequency. Similarly, the trend in EW has been toward wide bandwidth capability, where the jammer amplifies wideband noise or may deceptively retransmit the radar pulse to offset the radar's frequency shift tactics.

Since wide frequency bandwidths are essential to the employment of such tactics, an amplifying device capable of broad operating ranges with sufficient output power and efficiency was needed. The TWT offered promise in these areas; and the Navy was responsible for many of the primary advancements in the development of equipment to fulfill this promise.

PRINCIPLES OF OPERATION

Figure 7-12 is a simplified sketch of one type TWT structure. At the left of the diagram is the electron gun assembly. The cathode, when heated, emits a continuous stream of electrons. These electrons are drawn through the anode, focused into a tight, narrow beam, forced to travel the length of the tube, and eventually dissipate in the collector in the form of heat.

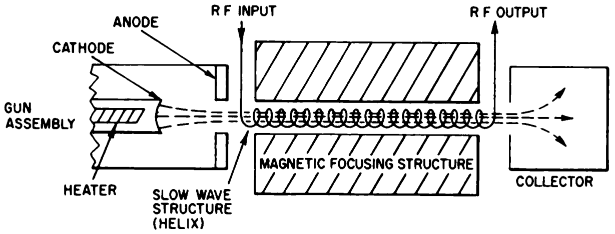

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Figure 7-12.–Schematic view of helix type traveling wave tube.

At the same time the electron beam is moving through the tube, the desired RF signal is fed into a slow-wave structure consisting (in this case) of a tightly wound wire called a HELIX. The phase velocity of the RF wave (or the speed at which the wave is moving forward) is slightly slower than the velocity of the electron beam.

An interaction is created between the electron beam and the RF signal. This interaction is such that the electrons in the beam are slowed by the RF field, and move down through the helix in bunches. As the electrons are slowed, they surrender energy to the RF field, resulting in great amplification of the RF signal by the time it reaches the output.

COMPONENTS

Basically, all traveling wave tubes consist of the same components, although there are many variations of each of these. These components are:

1. Electron gun, to produce the electrons and to shape them into a beam.
2. Slow wave structure, to propagate a microwave signal in such a manner as to permit interaction between the signal and the beam.
3. Collector, to absorb and eliminate the unused energy from the beam upon completion of its travel.
4. Input and output coupling devices for the transfer of energy into and out of the tube.
5. Attenuator, to isolate the input and output sections of the tube, so as to prevent undesirable oscillations.

These components and some of their variations are discussed in this section.

Electron Gun

The electron gun is the source of electrons for the beam, and is similar to the lens in a projector. Its main objective is to get as much electron current to flow in as small an area as possible, without distortion or fuzzy edges. A wide variety of gun designs have been developed in an effort to improve gun optics and to provide better beams.

Different types of cathode materials have been used as electron emitters. Two types have become generally standard: The oxide type, which has a nickel base with a barium-strontium coating; and the L-type (or dispenser) cathode which has an emitting surface consisting of porous tungsten through which barium atoms are dispensed from a chamber containing barium-strontium-oxide crystals. In addition, two other dispenser types, the pressed cathode and the impregnated cathode, are also used.

Recently a number of TWT's using control grids have been developed. This innovation permits turning the electron beam on and off rapidly with a smaller voltage swing than is required with cathode modulation of the tube without the grid.

Methods of Focusing

All TWT's require some method of holding the electron beam together as it travels through the interaction structure of the tube, because the beam tends to disperse (or spread out) as a result of the mutually repulsive forces between electrons. An electrostatic field or a magnetic field of the proper magnitude is used to confine the beam in the pencillike cylindrical shape it must maintain. The three principal types of magnetic focusing discussed here are shown in figure 7-13.

SOLENOID.–Solenoid focusing is still considered as one of the best means of obtaining a narrow, pencillike beam of electrons in an electron tube. The magnetic lines produced by the solenoid are parallel to the direction of travel of the electrons, and the solenoid can be alined accurately with the beam. This type focusing continues to be used in cases where the maximum power is required from the tube, and the physical size and weight of the tube and associated circuitry are not critical.

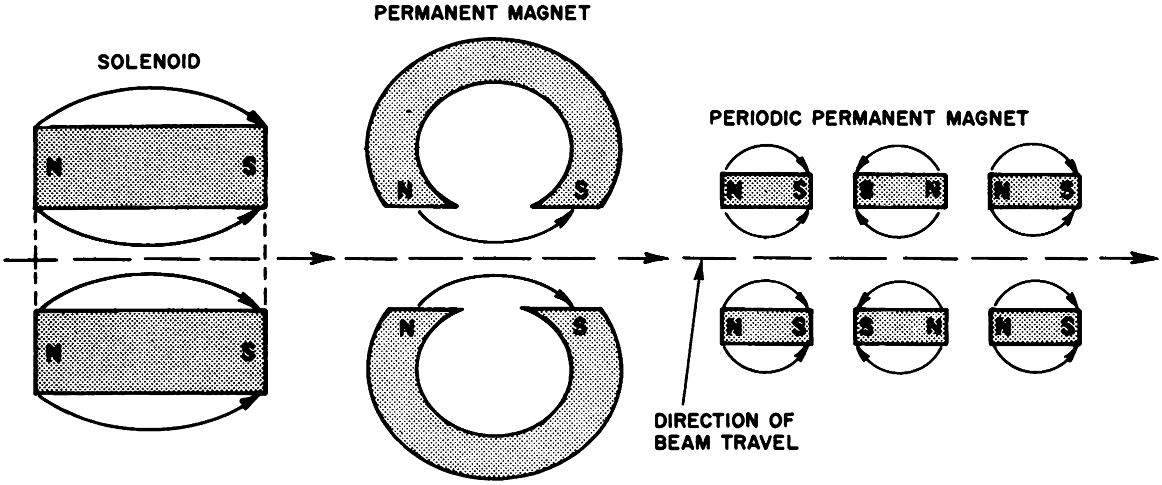

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Figure 7-13.—Types of magnetic focusing.

However, in airborne equipments, the solenoid type focusing has been supplanted by other means.

PERMANENT MAGNET.—Permanent magnet focusing is frequently used in tube structures where the interaction space is short. Extremely powerful magnets are required for this application, and the weight and physical size must not be excessive if the tube is to be used in airborne applications.

PERIODIC PERMANENT MAGNET.—Periodic permanent magnet (PPM) focusing is perhaps the most important new development in the evolution of beam control methods. In this method, small but powerful permanent magnets are placed at regular intervals along the slow wave structure of the tube. As the electron beam travels along the interaction space, it is acted upon by the magnetic fields which periodically focus it into a sharp beam. Figure 7-14 illustrates the construction and arrangement of this type focusing system.

This lightweight focusing method fills a great need in the high power systems where the focusing solenoids formerly required for the high density electron beam were too large and too heavy for many of the airborne and space applications. The tube shown in figure 7-14 (A) is a high power X-band TWT. The tube is a metal-ceramic type using the coupled cavity interaction space (discussed later), and weighing only about 15 pounds complete. Its magnetic structure is composed of round disks represented in the cross section by the black vertical areas at the ends of the interaction structure. These magnets are separated by the lighter-colored iron pole pieces, which not only act as magnet separators but also from the interaction structures of the tube.

A helix type TWT using PPM focusing is shown in (B) of figure 7-14.

ELECTROSTATIC.—Electrostatic focusing systems have been used with lower power and medium power traveling wave tubes, but some difficulty has been encountered at the high power levels. The electrostatic focusing system requires no magnetic field, and it is considered practical to make it even lighter and smaller than the PPM focusing system.

Slow Wave Circuits

Basically, there are two types of slow wave circuits used in traveling wave tubes. These are the HELIX and the FILTER TYPE. Each of these types has several variations, and each has its advantages and disadvantages. The particular circuit used is determined by the function of the tube and its associated circuitry.

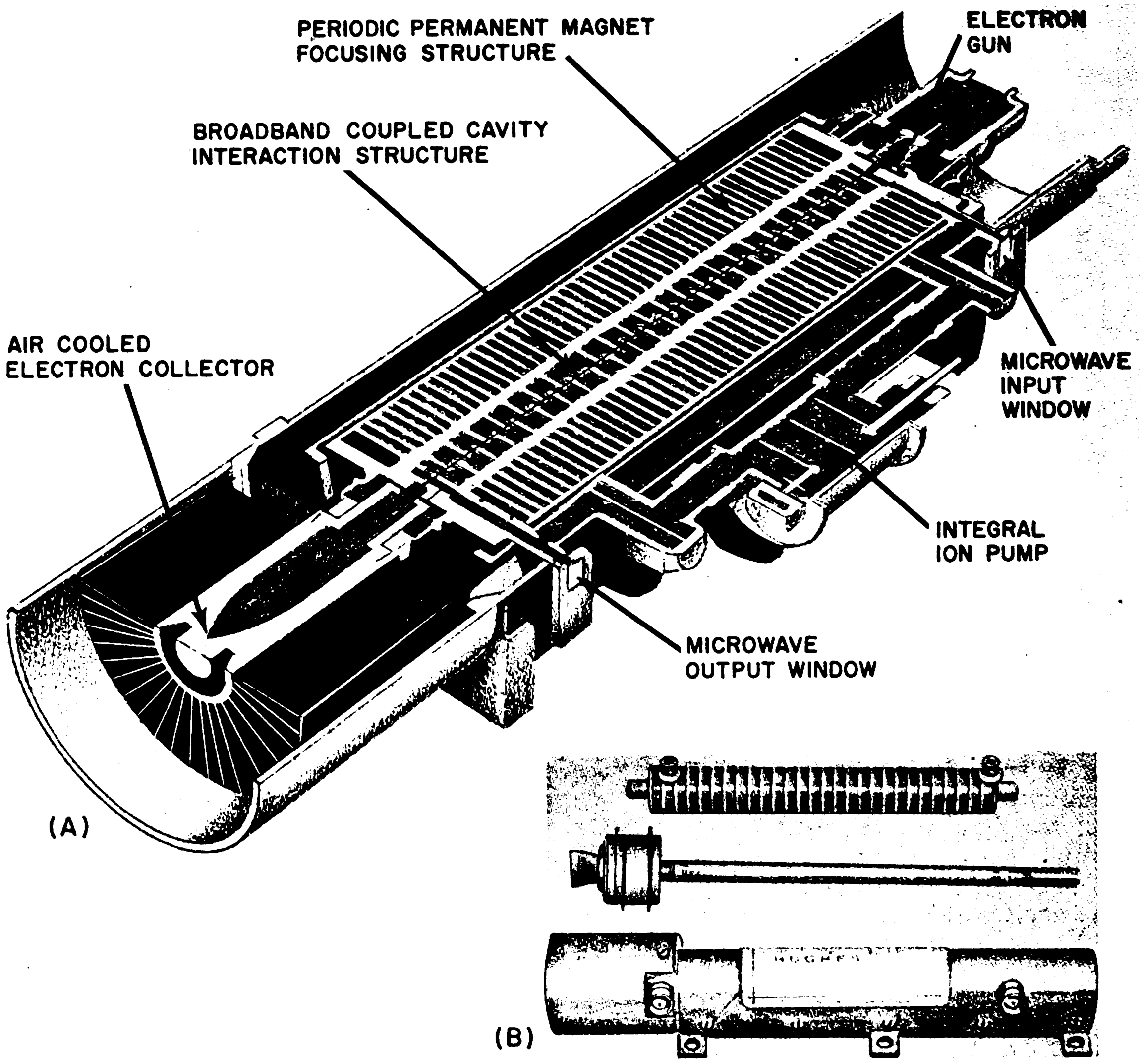
PERIODIC PERMANENT MAGNET FOCUSING STRUCTURE
ELECTRON GUN
BROADBAND COUPLED CAVITY INTERACTION STRUCTURE
AIR COOLED ELECTRON COLLECTOR
MICROWAVE INPUT WINDOW
INTEGRAL ION PUMP
MICROWAVE OUTPUT WINDOW
(A)
(B)

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Figure 7-14.—TWT's using PPM focusing system.

THE HELIX CIRCUIT.—The helix circuit gets its name from the fact that the structure which comprises the slow wave circuit is a coil of wire wound in the shape of a helix, or coil spring. The helix is considered to be the most efficient slow wave circuit for TWT applications. It is capable of producing wider bandwidths than any of the newer versions, but its use is limited by power output restrictions.

The helix is normally made of tungsten or molybdenum, and is wound to extremely accurate dimensions. The fields associated with the "slow waves" they carry must travel at approximately the same axial speed as the stream of electrons emitted from the cathode. For example, in a 1,500-volt electron beam, the axial speed at which the electrons travel is one-thirteenth the speed of light. Since the RF signal is carried along the wire from which the helix is wound at about the speed of light, the resulting linear ratio of the helix length to the beam length must be 13:1 in this example.

A number of configurations using the basic helix structure have been tested in an attempt to increase the power output capabilities of the tube. The CONTRAWOUND HELIX structure uses two helices wound in opposite directions, and effectively increases the power output capability of the tube to a moderate degree. The RING-BAR shown in figure 7-15 is one version of the contrawound helix.

One disadvantage of the helix circuit has been the fragile glass vacuum envelope which encloses the tube parts; however, such glass structures are sufficiently well supported to withstand almost any environment and can tolerate very high shock and loads. Recently a means of adapting metal and ceramic materials for use in the place of glass in the manufacture of TWT's has been developed. These tubes can withstand higher loads and can be fired at higher temperatures than before; this assures considerably better "cleanup" of undesirable gases trapped in the tube, and improved reliability at higher operating temperatures.

FILTER TYPE CIRCUITS.—The basic helix structure and its major variations have two main limitations when used at high power levels: the inherent tendency to oscillate, and the inability to dissipate the large quantities of heat accumulated. Several versions of the filter type slow wave circuit have shown great promise in overcoming these shortcomings, while maintaining the wide bandwidth of the traveling wave tube.

The simple waveguide is basically a high pass filter. If the waveguide is periodically loaded (loads placed along the guide in such a manner that the wave sees these loads periodically as it travels along the guide), reflections result from the loading devices. Thus, the high pass filter becomes a bandpass filter with specific characteristics which depend on the nature of the periodic loading utilized.

FUNDAMENTAL FORWARD WAVE circuits have been developed in which a disturbance of the basic waveguide mode is introduced at a point where the phase and group velocities of the wave are in the SAME direction. One of these circuits, the CLOVERLEAF (so called because the circuit couplers are connected so as to resemble a four-leaf clover), has achieved up to 2 megawatts peak power at S-band frequencies, over a 10-percent bandwidth (10 percent of the center frequency), with gains on the order of 20 to 30 decibels.

Another broad group of filter type slow wave circuits, called SPATIAL HARMONIC FILTERS, uses a coaxial mode which is distorted by the waveguide wall. The fundamental wave in these circuits has its phase and group velocities in OPPOSITE directions. Therefore, a harmonic (usually the first) is used. These circuits are used as BACKWARD WAVE AMPLIFIERS or as BACKWARD WAVE OSCILLATORS. Spatial harmonics should not be confused with frequency harmonics. Spatial harmonics are all approximately the same frequency, but are developed at different times as the electron bunch travels through the slow wave structure. Thus, they are related to the periodicity of the slow wave structure.

The SINGLE-SLOT, DOUBLE-SLOT, and DRIFT TUBES are examples of the spatial harmonic circuits. Double-slot TWT's have been built which produce 1 megawatt peak power output over a 9-percent bandwidth, with gains also in the 20- to 30-decibel region.

One of the most significant developments in recent years has been the utilization of basic waveguide mode resonators, coupled together by means of capacitive or inductive apertures, to provide either a fundamental forward or a backward wave circuit. This device is known as the COUPLED CAVITY CIRCUIT. It is also known as a FOLDED WAVEGUIDE circuit, since

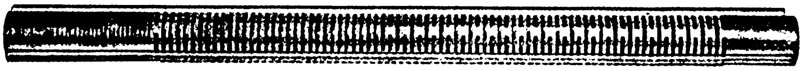

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Figure 7-15.—A contrawound helix.

its structure resembles a waveguide folded in accordion fashion. Figure 7-16 illustrates a cross section view of a high power, coupled cavity tube of the spatial harmonic variety.

Originally these structures provided frequency bandwidths on the order of 10 to 15 percent. Recently, however, means have been developed for increasing the bandwidth of these circuits to 40 percent and more; and tubes utilizing this circuit have produced several hundred kilowatts peak power in the S and X bands, with up to 50 decibels gain.

Another version of the coupled cavity circuit, the interdigital line, has found extensive use in low and medium power amplifiers ranging in power output up to 1 kilowatt peak, with gains of about 30 decibels.

The Collector

The only function of the collector is to dissipate the energy of the electrons in the form of heat as they emerge from the slow wave structure. This is usually accomplished by conduction to a colder outside surface, where the heat is absorbed by circulated air or liquid. The collector size is determined by the method of cooling used and by the amount of energy which must be released.

Coupling and Attenuation

Input and output coupling methods, and the means of attenuating signals in the TWT circuits, are generally of the same types discussed in Basic Electronics, NavPers 10087-C, Vol. 2, chapters 7 and 8. A review of these coupling and attenuating methods may be of some help at this time.

APPLICATIONS

The traveling wave tube has proved itself a very versatile device. Among the applications to which it has been put are:

1. Amplifiers–tunable and fixed frequency; input and IF; amplitude, phase, pulse, and frequency modulated; and phase and frequency shifters.

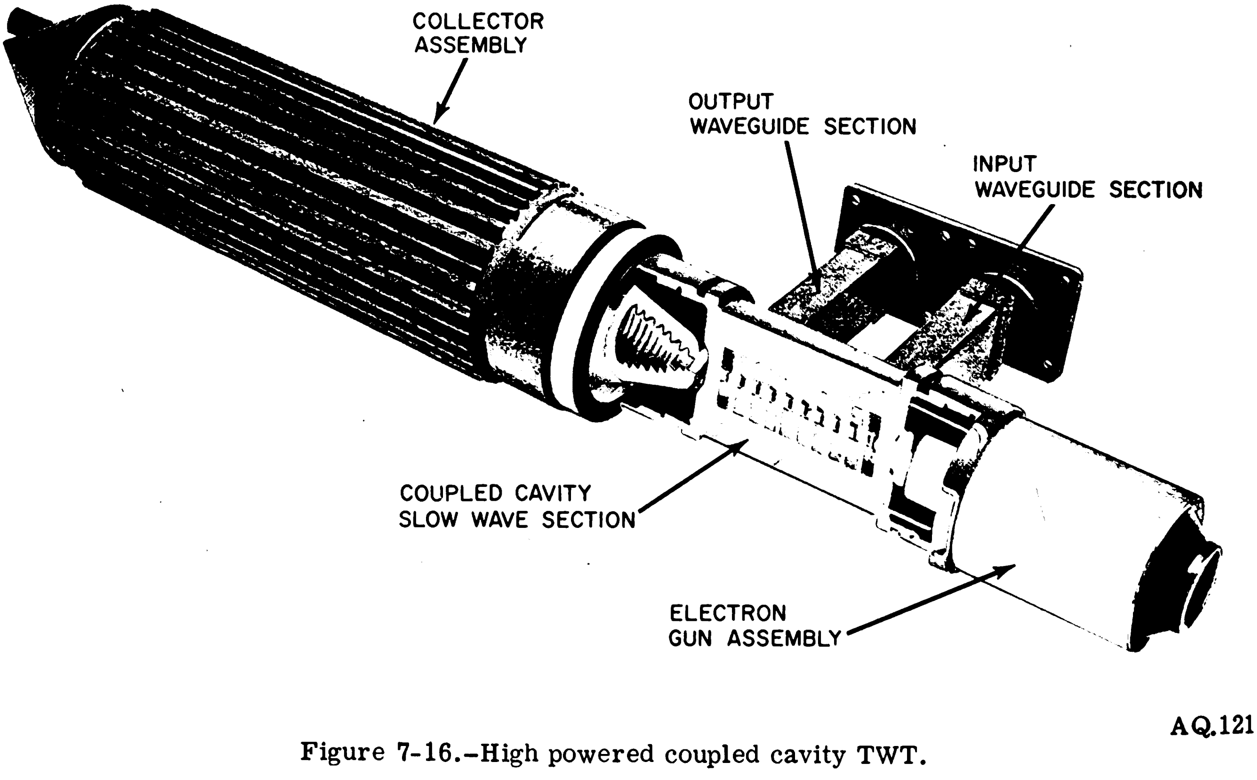


Figure 7-16.–High powered coupled cavity TWT.

2. Limiters and automatic gain control devices.

3. Microwave frequency generators–fixed frequency, narrowband or wideband, or tunable; frequency multipliers.

Some of these applications will be discussed in the following paragraphs, along with details of construction and variations of the tubes and circuit functions.

Amplifier

The most noteworthy characteristic of the traveling wave tube is its ability to amplify microwave signals through a wide band of frequencies. This amplification is obtained through the use of the interaction circuit. This circuit is basically a transmission line, and usually does not contain a resonant circuit of any kind. By avoiding the use of resonant circuits, the TWT is not subject to the normal gain-bandwidth formula (which states that as the bandwidth is increased, the gain decreases, and vice versa). To date, the TWT is the only amplifying device used at microwave frequencies that does not use resonant cavities for amplification. The gain-times-bandwidth product of the TWT may be in the order of 10^{13}. TWT's have been constructed to operate in frequency bands from 0.5 to 96 GHz.

In the helix type slow wave circuit (fig. 7-17), this gain takes place as described in the following paragaphs.

The electron beam is injected into the interaction region at the electron gun end of the slow wave structure. The velocity of the beam is determined by the d-c potential between the slow wave structure and the cathode of the gun. The beam is focused, by the focusing device, into a cylindrical beam whose diameter is

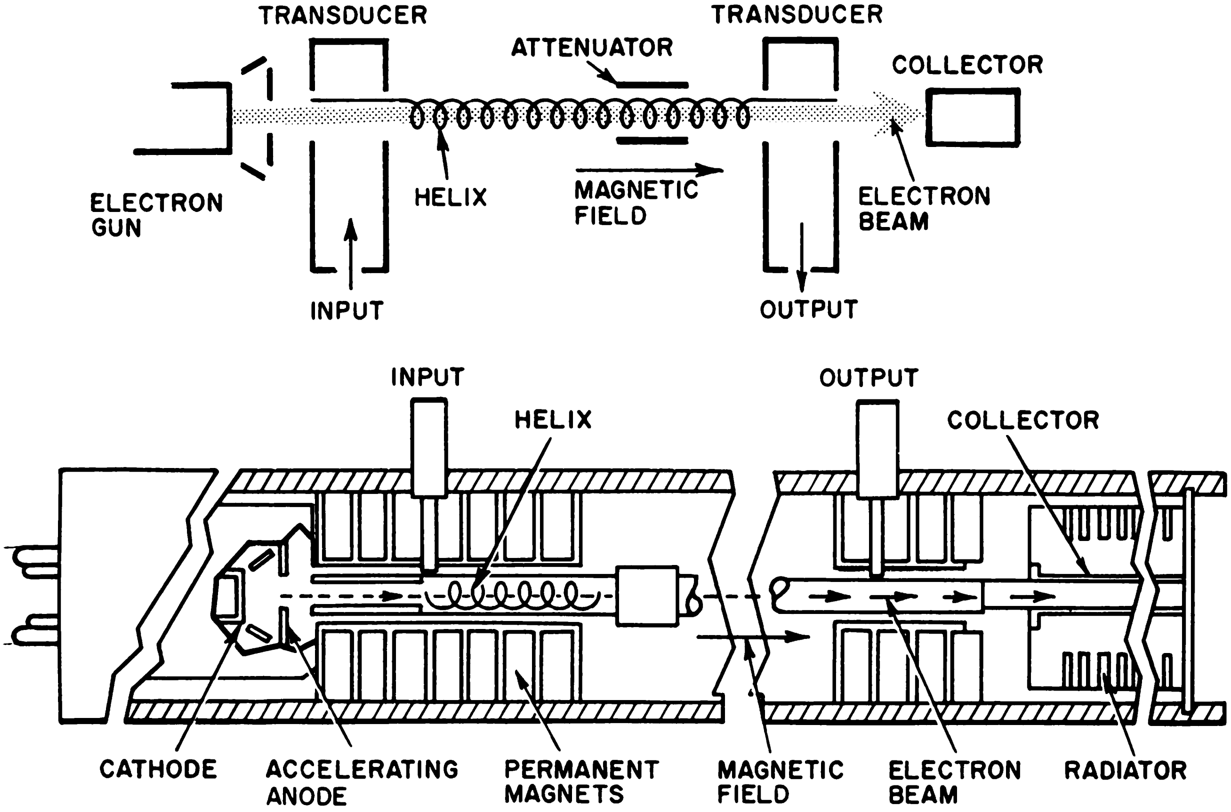


Figure 7-17.–Helix type TWT amplifier.

approximately the same as the diameter of the inside of the slow wave structure.

An electromagnetic wave is injected into the same region at the gun end, and travels along the circumference of the slow wave structure at nearly the velocity of light. Due to the physical construction of the slow wave structure, the electron beam (in its direct path) and the electromagnetic wave (in its longer path) travel together along the slow wave structure at approximately the same forward velocity. The beam accelerating potential is adjusted so that the beam velocity is slightly greater than the wave velocity.

As in the magnetron, interaction of the RF electric field upon the electron beam will result in the acceleration of electrons in certain regions, and deceleration of other electrons in other regions. As the beam progresses along the slow wave structure, the decelerating action becomes predominant, and d-c energy from the electron beam is transferred to the RF electric field, resulting in amplification of the RF input signal.

Saturation may occur in a TWT, as in other types of electron tubes. In the TWT, this condition results from the RF field becoming excessive, due to either too large an input or too much gain. This represents the maximum power output of the tube for a given value of beam current. An increase in beam current will permit a further increase in output power, but the increases are not linear functions. For low input levels the gain is nearly constant, while the gain becomes less at higher input levels. Increasing the input beyond the saturation point results in decreased power output.

Maximum gain that can be realized from a TWT circuit is dependent on, and limited by, the following conditions:

1. The beam current value at which the tube will oscillate.

2. The maximum emission limit of the cathode.

3. The maximum beam current that can be focused without excessive heating of the tube elements due to the currents into these elements.

TUNABLE AMPLIFIER.-Using the TWT, it is possible to obtain high values of gain over a broad tuning range by varying the slow wave voltage. Use of a narrowband TWT decreases the danger of oscillation and permits greater gain to be obtained, but over a restricted frequency range. The wideband TWT permits high values of gain to be obtained over a greater range of frequencies, but the danger of oscillation is increased.

IF AMPLIFIER.-All pulse amplifiers require wide bandpass characteristics, and the more narrow the pulse, the wider the passband require of the amplifier. The TWT seems to be especially well adapted for use in this type circuitry, and has been used successfully as an IF amplifier, replacing the complex (and frequently troublesome) assemblies normally used for that purpose.

INPUT AMPLIFIER.-When used as the input amplifier of a radar receiver, the TWT must be able to respond linearly to input power levels over a wide range. Due to the limiting action of the TWT, however, modulated inputs with high power levels result in distortion. This disadvantage may be decreased by use of a varying helix voltage which extends the saturation point beyond the largest anticipated input. (This method is not applicable to phase sensitive radar systems.)

Low noise TWT's are especially useful in the input circuits of radar receivers because of the low noise figure throughout the life of the tube, and the additional protection of the crystal mixer following the TWT.

MODULATION.-In traveling wave tubes operating under CW conditions, the broadband circuit has an essentially constant phase angle. Since the interaction circuit is electrically quite long (usually at least 10 wavelengths), a slight variation in beam velocity can produce an appreciable variation in phasing at the output end of the structure. This is known as PHASE MODULATION. The allowable limits of variation are determined by the circuit.

AMPLITUDE MODULATION of the TWT may be accomplished by merely varying the potential applied to the electrode which controls the beam current. Generally, high percentages of modulation may be obtained from this method.

PULSE MODULATION is accomplished by pulsing the beam accelerating potential, or by pulsing the cathode with respect to the other electrodes. Pulsed tubes normally operate at the same potentials as would be used for the same tube operating under CW conditions. Peak power output in pulsed circuits may be increased only by increasing beam current, but this is practical only through comparatively narrow limits.

SAWTOOTH PHASE MODULATION results from applying a sawtooth wave to the slow wave element. The phase of the signal is continuously advanced, simulating an increase in frequency. This method is effectively the basis of single sideband modulation. It may also be used to simulate Doppler effect.

FREQUENCY SHIFTING.--This is accomplished in the same manner as phase modulation, the only difference being in the application and output circuitry. If the slow-wave-to-cathode impedance is low at the desired shift frequency, it may be possible to drive the cathode along in order to obtain the required output. Additional changes in phasing result from these variations in beam current.

DYNAMIC PHASE SHIFTING in the TWT occurs whenever amplitude or pulse modulation is the result of changing the beam current, the slow wave circuit voltage, or the anode voltage.

STATIC PHASE SHIFTING may occur as a result of differences in the effective lengths of the slow wave circuits or of the input and output coupling devices.

LIMITING.-Due to the saturation characteristics of the TWT, relatively constant output power may be obtained over a wide range of input power levels. By a slight modification of the basic TWT, this limiting action may be significantly increased. Use of two TWT's connected in cascade permits the level of output power to be held constant within 0.5 db over a 50-db range of input power and a 25-percent frequency variation.

AUTOMATIC GAIN CONTROL (AGC).-The limiting action of the traveling wave tube may be enhanced by the use of a feedback voltage applied to the electrode which controls beam current. Such a configuration is called an automatic gain control circuit, and is used when a constant power output level is required.

Microwave Frequency Generators

If a small part of the output is fed back to the input (through a directional coupler, a resonant cavity, and a phase shifter), stability of an oscillator can be improved. The total RF phase shift must be controlled so as to assure regenerative phasing at the input, and loop loss must be controlled in order to provide the proper magnitude of feedback signal. These requirements may be met by incorporation of a variable phase shifting network and a variable attenuator.

Phase shifting in the circuit may result from any of the following (or any combination of them):

1. Transmission line delays. These include phase shifts due to the length and the distributed constants of the transmission line system, the helix structure, the couplers, etc.
2. Resonant cavity or filter delays.
3. Electronic phase shifting resulting from any changes in the potentials applied to the electrodes.

Use of a filter having a wide bandwidth and low losses allows electronic tuning by merely varying the helix voltage. If the filter is of a narrowband type, tuning may be done manually.

As the output of a TWT approaches its saturation point, frequency harmonics are produced. Conversion gains of about 10db can be obtained when the tube is used as a frequency doubler, with somewhat less gain for higher order harmonics.

BACKWARD WAVE OSCILLATOR

The "M" type backward wave oscillator (M-BWO) is a wideband, high powered, highly efficient and reliable source of microwave power. It offers high speed, half-octave electronic tuning by variation of a single control voltage. Its most extensive application to date has been in ECM barrage and spot noise jamming.

During World War II, the magnetron, with mechanical tuning, was the workhorse of the microwave electronic warfare equipment. However, because wide and rapid tuning requirements began to develop for both radar and countermeasures, wideband electronic tuning of high powered microwave oscillators became desirable.

The development of the voltage tunable magnetron and the principle of traveling wave interaction in linear beam tubes stimulated work on crossed field traveling wave devices. This led to the development of the CARCINOTRON, and M-BWO.

The M-BWO has become an excellent microwave ECM transmitter tube because of the following characteristics:

1. The advantage of the M-BWO's voltage tuning over mechanical tuning.
2. The tube's high power and efficiency.
3. Its versatility.
4. Its economy of size and weight.

APPLICATIONS

Noise jamming is a brute force method of jamming which supplies sufficient noise to radar receivers to make it difficult to distinguish target echoes. The noise RF power is obtained by frequency and/or amplitude modulating the M-BWO with a noise source and a sine wave source. The noise bandwidth can be varied about the operating frequency, thus providing a high degree of flexibility in terms of watts per megahertz versus bandwidth. The two basic modes of operation are spot or narrowband jamming, and barrage or wideband jamming.

BASIC PRINCIPLES

The M-BWO is a voltage tunable microwave power generator using the interaction of a ribbon beam traveling near a frequency selective delay line. Electric and magnetic fields are maintained at right angles to each other and to the direction of the beam. The beam velocity is substantially the same as the phase velocity of a wave component traveling along the delay line. By this means, energy is transferred from the static field to the RF field. In the M-BWO, the RF energy travels in a direction opposite to that of the electron beam.

In most practical tubes, the interaction space is ring shaped. Figure 7-18 (A) shows a cross section of a typical tube and shows the path of the electron beam and the RF energy under oscillating conditions. Figure 7-18 (B) illustrates a three-dimensional cross sectional view of an earlier M-BWO.

The M-BWO is a member of the traveling wave tube family described earlier in this chapter, having in common with it the slow wave device, or delay line, and the bunching of electrons in the beam. The M-BWO differs from the TWT in several ways, including the use of the crossed magnetic field. You will probably recall that crossed magnetic fields are also used in the magnetron.

BACKWARD WAVE OSCILLATOR

The principle of traveling wave interaction is basic to all crossed field devices. The major objective is to convert electrical energy from static (d-c) form to electromagnetic energy in extremely rapid (microwave frequency) alternating form. The electron is used for this power conversion, since it is able to link the two forms of energy. Reacting initially to the input or static conditions, it takes energy from the input and transports it to another part of the device. Here the energy can be drawn upon to create an output or to amplify microwave signals.

Two elements which require further explanation have been introduced: the path of the electron from its source to its final destination, and the "other part of the device" where the energy of the electron is finally utilized. Each will be considered in turn; then the combining of the two elements to form a working microwave tube will be discussed.

The Electron Path

The path of the electron can best be understood by considering the forces acting upon it. Refer to figure 7-18 (A). The source of all electrons is the cathode. Properly designed and located, the cathode supplies a unidirectional stream of electrons. Immediately after the electrons are emitted, the combined action of magnetic and specially shaped electric fields forms them into a beam.

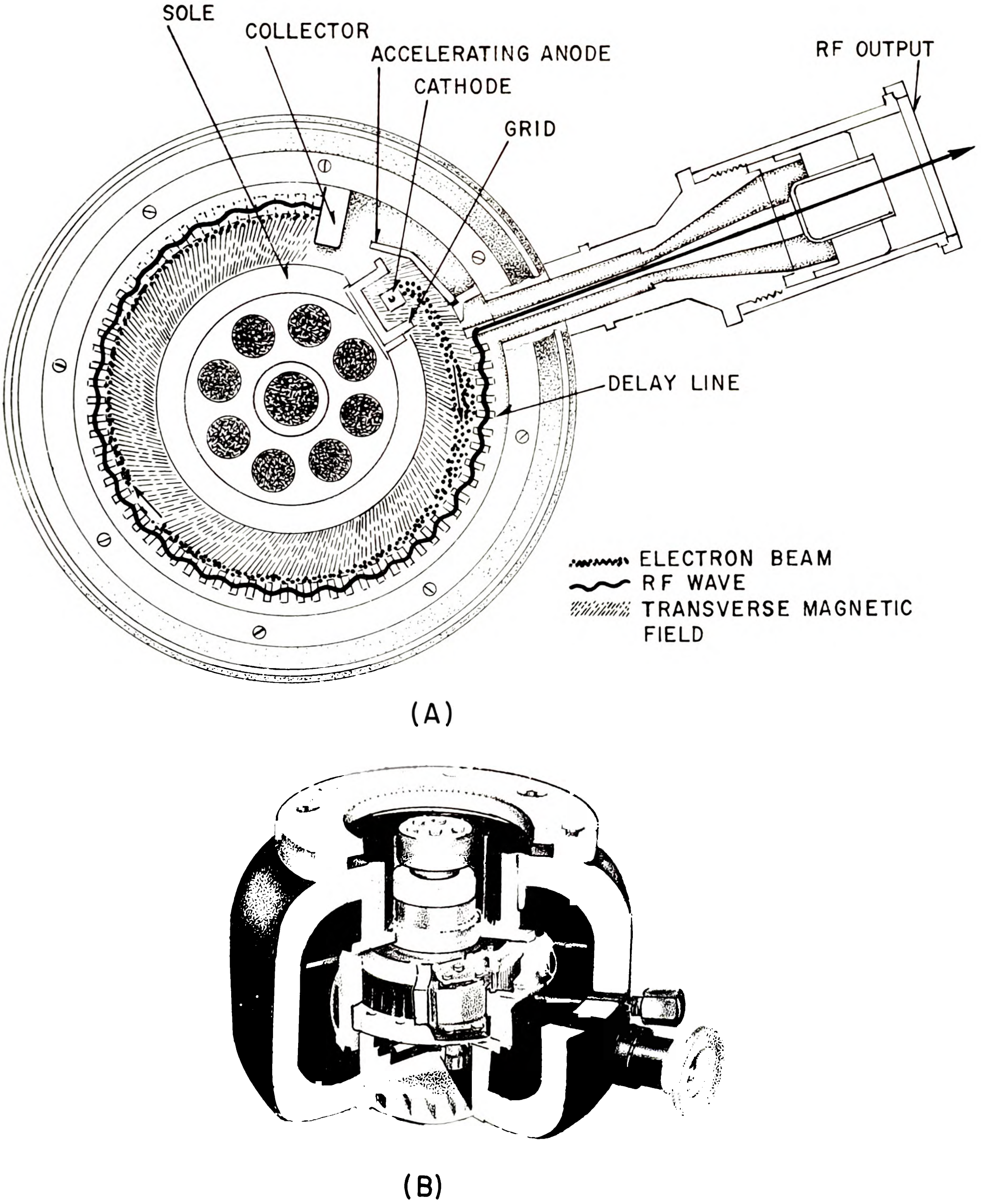
After the beam is formed, all of the component electrons travel at approximately the same velocity. The negatively charged electrons are injected into an electric field which is perpendicular to their forward motion. (This field arises from voltages applied between opposed elements, the anode and the sole, and in the absence of other forces a given electron would soon be "collected" by the positive element, the anode.)

However, a second force acting upon the electron arises from its forward motion through a magnetic field oriented crosswise to both the electron path and the previously described electric field; hence, the term "crossed field" tube. By the conventional rule for this situation, the resultant force on the electrons is opposite to the force of the electric field.

Appropriate adjustment of the fields results in a controlled beam path which is circular and terminates at an element called a collector.

To summarize, the electron beam is formed at the electron gun (cathode), follows a circular path between the anode and the sole, and terminates at the collector.

When the forces acting on the beam are expressed in standard electrical terms and equated for the controlled beam condition, the electrical force equals the magnetic force. Therefore, electron or beam velocity is equal to the ratio of electric field strength (E) to magnetic field strength (B). For the practical situation, B is constant and is supplied by a permanent magnet integral with the tube. Thus, beam velocity is directly related to E, the field



(A)

(B)

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Figure 7-18.—Typical M-type backward wave oscillator.

strength between sole and anode. In more practical terms, E is given by the potential difference between the anode and the sole, divided by the distance between them (which is fixed). Therefore, beam velocity is linearly controlled by variation of either the anode voltage or the sole voltage.

The Delay Line (Anode)

The next step in understanding the basic principles of the crossed field device is to consider the part of the device where the electron beam develops microwave energy.

The sole serves as little more than one of the electrodes for the static electric field as discussed in the previous section. The anode, however, is a much more complex component than has been suggested. The anode in many crossed field tubes is of such a form that it is called an INTERDIGITAL DELAY LINE.

The interdigital delay line is best described as a normal waveguide transmission medium in which opposing walls have been extended towards one another in alternately spaced fingers or digits, as shown in figure 7-19. The velocity of wave travel in the resulting interdigital structure is decreased, because of the longer path along its boundaries. In effect, such a structure develops a series of space harmonics whose summation is seen as microwave energy propagated at the delayed or reduced rate.

(One type of magnetron, called the INTERDIGITAL MAGNETRON, uses the interdigital transmission line as the interaction space in the generation of RF power. The action of that device is more or less a combination of the conventional magnetron and the backward wave oscillator.)

A particular delay line can be designed for either forward wave or backward wave propagation. The distinction between the two arises from comparison of the direction of the dominant space harmonic with the direction of the energy which sustains it.

The amount of delay is established by adjusting various dimensions within the line. As with the more familiar waveguide, the delay line is a broadband device capable of transmission over a considerable frequency range. Its physical shape is a matter of convenience and, in this case, it is circular.

Production of the space harmonics is the same as in any oscillator, starting with noise and leading to generation of usable frequencies. These frequencies are determined by the fields of the device in a manner similar to the action of a magnetron.

In brief, the electrons serve as a link between the externally applied input energy and the microwave output energy. The electrons determine, by their velocity, the output frequency in an oscillator (and the optimum frequency for an amplifier). At the same time, they determine by their quantity (beam current magnitude) the power output level.

In contrast with magnetrons, the use of a beam in crossed field tubes eliminates cathode back bombardment, thus increasing emission life. In comparison with linear beam devices such as a traveling wave tube, where beam velocity (and therefore tube frequency) are functions of the square root of the tuning voltage. BWO's provide a very nearly linear relationship between tuning voltage and tube frequency.

Interaction

As the electron beam travels in a circular path between the sole and the anode (delay line), electrons of the beam pass near the fringe fields of the noise generated space harmonic waves on the delay line. For electrons of a given velocity, as determined by the externally applied delay

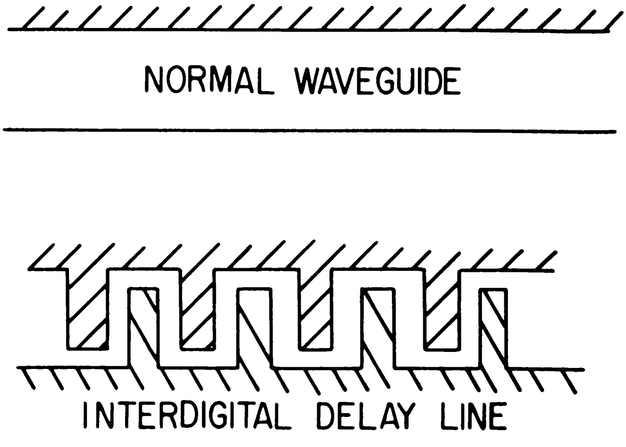

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Figure 7-19.—Interdigital delay line compared with a normal waveguide.

line voltage, space harmonics of synchronous phase velocity result. Whether these are forward or backward waves is determined by the design of the delay line. In either case, since phase velocity of space harmonic waves is, in general, a function of frequency, it is the velocity of the electrons that determines the operating frequency.

The total field in this case is a combination of the externally applied fields and the internally developed space harmonic field. By following the laws governing electron motion in crossed electric and magnetic fields, electrons drift in a direction perpendicular to the space harmonic fields. This drift is such that they congregate in bunches, one bunch per space harmonic wavelength.

In the bunches, electrons work their way across from the original beam position to the slow wave structure (delay line), staying locked in synchronism as they do so. Their direction of motion is such that they give up to the RF field the energy acquired from the d-c source, thus causing the space harmonic wave to grow.

PHYSICAL AND ELECTRICAL CHARACTERISTICS

The basic elements of the M-BWO together with the usual polarities of applied d-c voltages, are indicated in figure 7-20. The arrangement of the basic elements can be separated into three regions as follows:

1. The gun region, including the cathode, grid, and accelerator.
2. The interaction space, including the delay line and the sole.
3. The collector element and the sole.

In practical tubes, the collector and the delay line are integral parts of the tube body and are maintained at ground potential. An exception is that the "beam miser" (to be discussed later in this chapter) places the collector at cathode potential.

The electron gun comprises a heater, cathode, control grid, and accelerator anode. The control grid is operated at zero potential or slightly negative with respect to the cathode. The accelerator electrode is maintained at a positive potential with respect to the cathode. The sole electrode is negative with respect to the cathode, and the delay line (commonly referred to as an anode) is positive with respect to the cathode.

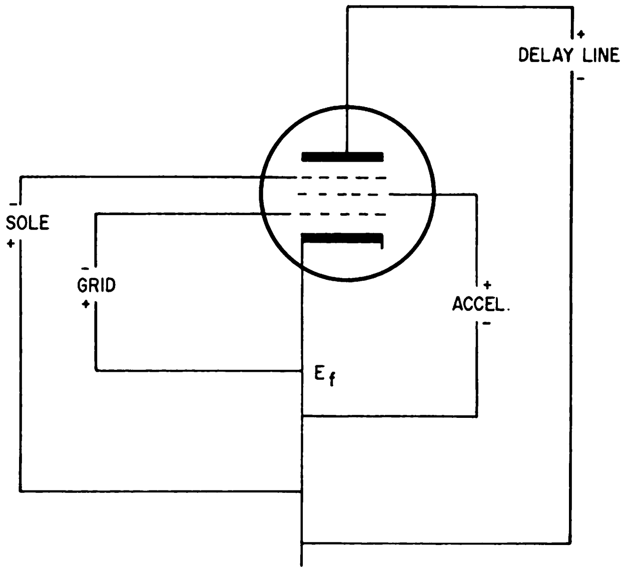

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Figure 7-20.–Schematic equivalent of an M-BWO.

With appropriate values of applied potentials and appropriate value and direction of magnetic field, the electron beam is formed in the gun regions, passes through the interaction region, and is collected at both the delay line and the collector.

In backward wave oscillators there is no RF input, and a portion of the delay line adjacent to the collector is modified to assure absorption of any power reflected from the output.

The principal projections from the main tube body are the RF output connector and the HEADER, through which the electrode leads are brought out to external terminals. A doughnut shaped magnet is used, since this form combines high internal magnetic field strength with excellent external magnetic self-shielding properties.

FREQUENCY TUNING AND MODULATION

The oscillator can be tuned through the designed range of frequencies by varying the delay line-to-cathode or sole-to-cathode potential. This can be done statically or dynamically at rates limited chiefly by modulating power and interelectrode capacitances.

The average rate of tuning for a given tube design will be nearly linear throughout the range and very similar from tube to tube. The sensitivity differs in present tubes of different frequency ranges from approximately 0.13 MHz per volt at L-band frequencies to approximately 1.0 MHz per volt at X-band frequencies. The sole potential can be varied for frequency modulation with the advantage of requiring less modulating power. Since frequency is determined by the anode-to-sole potential, both sole and anode (delay line) tuning sensitivities are essentially the same. Sole modulation is limited to one-half of the complete tuning range of the tube, due to tube electronic characteristics.

Amplitude Modulation

Amplitude modulation is accomplished by varying the accelerator potential, since this electrode controls delay line current. Accompanying the amplitude modulation is an inherent frequency modulation resulting from frequency pushing. (Frequency pushing is defined as an RF frequency variation due to a variation in anode current.) Pushing is not linear over either the frequency range or the current range. Amplitude modulation linearity is good, but may be limited at low modulation frequencies by cathode fatigue during high current peaks. The grid electrode should not be utilized for amplitude modulation purposes. A d-c potential on the grid may be required for optimum tube efficiency.

Pulse Modulation

Although these tubes have been designed primarily for CW operation, it is possible to pulse the accelerator electrode and obtain peak power output considerably in excess of the CW power. Some delay line current is present even at zero accelerator potential. In some cases, therefore, it may be desirable to bias the accelerator negatively to obtain complete cutoff, and pulse positively from the level of cutoff bias.

INSULATION AND COOLING

Normal heat dissipation, principally at the delay line and collector, usually requires that external liquid cooling be provided to this region. A coolant channel, an integral part of the delay line, serves this purpose, with coolant being provided through external connections. The coolant generally used is Dow Corning 200 silicone oil, a thermally stable oil with a high resistance to change in temperature. For high altitude operation, the input bushing can be pressurized or immersed in an insulating liquid. In some applications, the tube is operated with the cathode at ground potential. When this method is used, primary to secondary high voltage insulation of the various supply transformers is unnecessary; but high voltage isolation of the RF output connector is necessary and additional safety precautions are required.

SPECIAL CONSIDERATIONS

Most microwave tubes have characteristics which limit their use or which require special consideration in their use. The following is a list of these factors, which the designer must bear in mind as he uses the tube in a system and which are also of interest to the operator:

1. Voltage tuning sensitivity at X-band frequencies is approximately 1 MHz per volt. Thus, for a CW signal, the power supply must be well regulated, with a low ripple factor. Although the average tuning sensitivity is nearly linear over the frequency range, there are variations in sensitivity for small frequency changes.
2. The sole current changes in magnitude with frequency tuning, and it can be in either direction.
3. Frequency pushing results from variations of other tube parameters. This may or may not be significant.
4. Interelectrode leakage current of a small value exists in tubes of present design.
5. A small amount of frequency pulling is a characteristic of the M-BWO. These tubes are, therefore, somewhat susceptible to load VSWR (voltage standing wave ratio) variations. Generally, load isolators are not required when load VSWR's are equal to or less than 1.5 to 1.
6. After full beam current has been established, stabilized frequency will be reached in 2 minutes or less.
7. Interelectrode capacitances must be considered as modulating frequencies are increased.
8. Power output varies over the tuning range primarily due to the necessary change in input power when tuning. Therefore, a 3-db power variation may be encountered over the tuning range.

THE BEAM MISER

The BEAM MISER is a unique type of depressed collector utilized in the beam type, crossed field traveling wave tubes. It permits significant increase in efficiency and power with no additional external connections or other changes in tube or circuit. The depressed collector is one which operates at a lower voltage than the anode or delay line, rather than at the same voltage.

The beam miser consists of a collector internally connected to the cathode and consequently at cathode potential. Thus the anode current is reduced for a given beam current, or the beam current is increased for a given anode current. In an analogous sense, the beam miser has some of the advantages of a reentrant electron beam in crossed field tubes. A considerable part of the spent beam which is unused can be returned to the cathode instead of being wasted by normal collection at anode potential.

The use of a beam miser in standard M-BWO's has permitted increases of power of the order of 30 percent for normal operating anode currents. It has also permitted suitable operation of one tube at several power levels; that is, multiple operating current capability. A tube with a beam miser requires no external mechanical changes or additional electrical input connectors and is, therefore, directly replaceable in the same socket as a standard tube not having a beam miser.

MODULATING OSCILLATORS

Oscillators are an indispensable part of most electronic equipments. However, in order to make the most use of the oscillator, it is necessary to insert some form of signal waveform that is used to convey information, messages, timing data, or whatever intelligence that must be transferred from the transmitter to the receiver. Without this added information, the oscillator would in most cases be of no value. There are many types of modulation techniques employed in airborne electronics—amplitude, frequency, phase, single-sideband, etc. The major part of this section is devoted to the pulse modulation techniques most often employed in radar systems. The line-pulsing modulator is discussed in chapter 9 of this manual.

Basically, there are two methods of pulsing UHF and microwave oscillators. The first method to be discussed is that used in the self-pulsing oscillator, which contains within itself the circuitry needed to permit oscillation for a period of time and to quench oscillation periodically. This ON-OFF action results in pulses of energy in the form of radiofrequency oscillations for a period of time, followed by no oscillation. The second important method of modulating UHF and microwave oscillators incorporates the use of separate modulator circuits to trigger the oscillator into its ON-OFF states of operation.

SELF-PULSING OSCILLATORS

Most oscillators use grid leak bias or a combination of grid leak and fixed bias. One advantage of grid leak bias is that the amplitude of oscillation is limited and stabilized. Notice the graphs of plate current and grid voltage versus time in figure 7-21 (A). These waveshapes are essentially the same for all oscillators using grid leak bias.

At zero time, plate voltage is applied but the grids are grounded so that a steady plate current flows. At time t_1 the ground is removed, and any random change in plate current will cause a change in voltage in the plate tank circuit, a portion of which is fed back to the grid circuit. Since this feedback is in the right phase and amplitude, the oscillations will grow in amplitude. Each time the grid goes positive, grid current flows and charges the grid leak capacitor more negatively so that on each successive oscillation the average grid voltage (the bias) goes more negative.

This continues until a balance is reached, and just enough grid current is drawn to replace the charge which leaks off through the grid leak resistor during the remainder of the cycle. As the average grid voltage becomes more negative, the plate current flows for a shorter portion of each cycle until the flow is just sufficient to replace the energy lost in the tank circuit and to supply feedback to the grid circuit.

With perfect circuit elements and smooth electron emission, the circuit would oscillate indefinitely at this amplitude. But minute irregularities occur in the movement of electrons through resistors and conductors; also the emission from a cathode is not uniform. The nonuniformity is slight, but it does affect the equilibrium in the oscillator circuit. Any slight decrease in current decreases the feedback; and if the time constant of the RC circuit is not

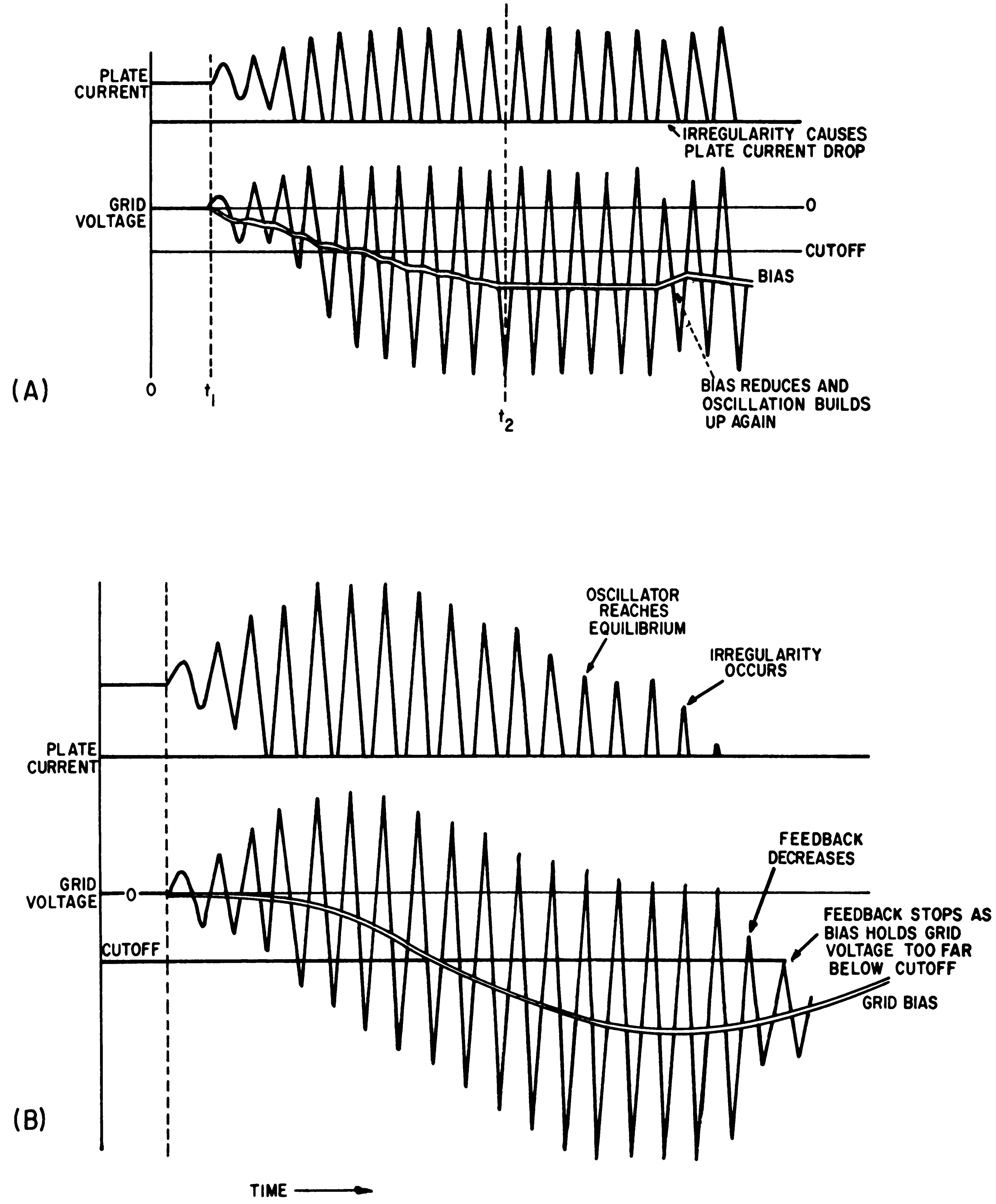
PLATE CURRENT
IRREGULARITY CAUSES PLATE CURRENT DROP
GRID VOLTAGE
0
CUTOFF
BIAS
BIAS REDUCES AND OSCILLATION BUILDS UP AGAIN
(A)
0
t1
t2
OSCILLATOR REACHES EQUILIBRIUM
IRREGULARITY OCCURS
PLATE CURRENT
GRID VOLTAGE
0
CUTOFF
FEEDBACK DECREASES
FEEDBACK STOPS AS BIAS HOLDS GRID VOLTAGE TOO FAR BELOW CUTOFF
GRID BIAS
(B)
TIME

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Figure 7-21.-Plate current and grid voltage versus time.

extremely long, the bias is reduced slightly by discharge of the capacitor. The decrease in bias allows a little more plate current, which reestablishes the equilibrium at the previous level.

In a circuit with a long RC, however, the circuit starts oscillating, then settles down to a balanced condition as previously described, but any slight decrease in plate current will not be compensated by lowered bias (as shown in fig. 7-21 (B)). The capacitor discharges slowly, and the continued high bias prevents feedback from being restored to the proper level. After a few cycles the oscillation dies out completely. The capacitor slowly discharges, and when its voltage drops below the cutoff voltage, the current again flows and the process repeats.

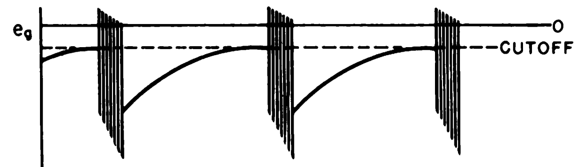
For continuous operation, the RC of the self-biasing circuit must be short enough to allow automatic adjustment of the bias for changing conditions in the circuit. To make the circuit oscillate briefly, then stop, a long RC ~~is~~ used. The time the tube remains cut off depends upon both the grid capacitance and grid resistance. By proper selection of these values, the oscillator may be made to operate for 1 or 2 microseconds and then cease operation for 500 to 1,000 microseconds.

Grid voltage variations are shown in figure 7-22. It is not possible to show the actual time relations, since the OFF period is several hundred times as long as the ON period.

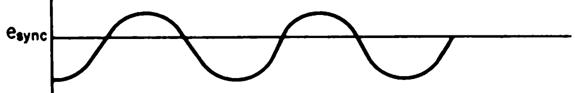
In an equipment using a self-pulsing oscillator it may be necessary to synchronize the oscillator with other circuits. This may be done by applying a synchronizing sine wave to the grid. The results are shown in figure 7-22 (B) and (C). Without synchronization (A), the grid rises exponentially and crosses the cutoff line at a small angle, which means that the actual time at which oscillation begins may vary somewhat. Notice in (C) that the point at which the grid voltage crosses the cutoff bias line is much more definite.

The ideal condition would be for the grid voltage to cross the cutoff line at a 90° angle. For that reason, a positive going pulse is often applied when the grid voltage approaches cutoff. This assures oscillation at exact intervals of time. The oscillator is then synchronized to produce a desirable PRF.

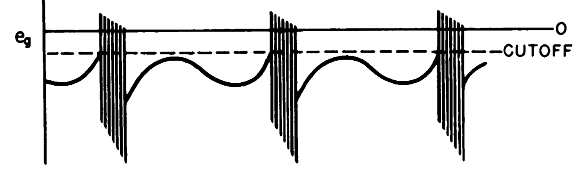
Another means of obtaining a sharp crossover angle of the grid voltage is to return the grid to a positive voltage rather than to ground. Thus the grid voltage, in rising to a higher voltage than zero, will cross the cutoff line at a steep angle.



(A) GRID VOLTAGE WITH NO SYNCHRONIZATION



(B) SYNCHRONIZING SINE WAVE



(C) GRID VOLTAGE WITH SYNCHRONIZATION APPLIED

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Figure 7-22.—Grid waveshape with and without sync.

In order to make the DURATION of the pulse more definite, some self-pulsed oscillators use an artificial transmission line (pulse line) instead of the grid leak capacitor. This has the added advantage of making the operating conditions more nearly constant throughout the pulse. There are two places where the pulse line can be located. One is to put it in the grid circuit, as shown in figure 7-23, the other, in the cathode circuit.

A pulse line behaves like a long transmission line. It acts like a resistive circuit until the charging pulse has traveled the length of it and returned, at which time it is fully charged. This causes the voltage to change in two steps; the first step is from the bias level to the voltage determined by the product of the grid current times the characteristic impedance of the line, and the second step is of a magnitude equal to the first.

The PRF is controlled by the synchronizing pulses, but the discharge of the pulse line through the grid resistor must be such that the grid voltage approaches the cutoff point by the time the next synchronizing pulse comes in. The discharge of the line is in steps, as shown in figure 7-24, which is the diagram of the grid waveshape

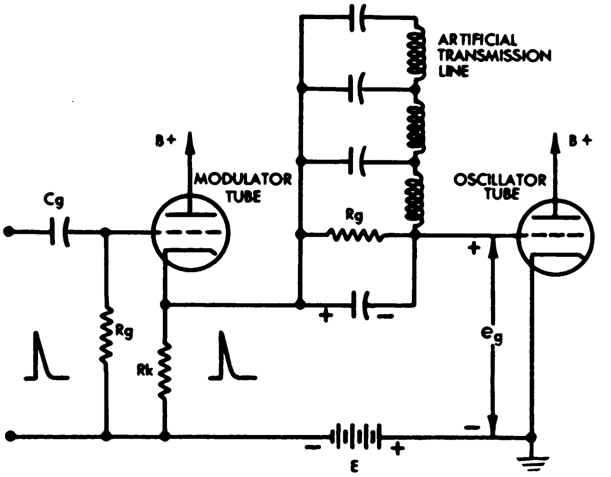

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Figure 7-23.—Oscillator, with pulse line in grid circuit.

of a line controlled, self-pulsed oscillator. The magnitude of the discharge voltage is determined by the relative values of the grid resistance (R_g) and the characteristic impedance of the line. R_g is usually much larger, hence the steps are small. These steps follow the general path of the exponential discharge curve with time constant R_gC_O, where C_O is the capacitance of the pulse line.

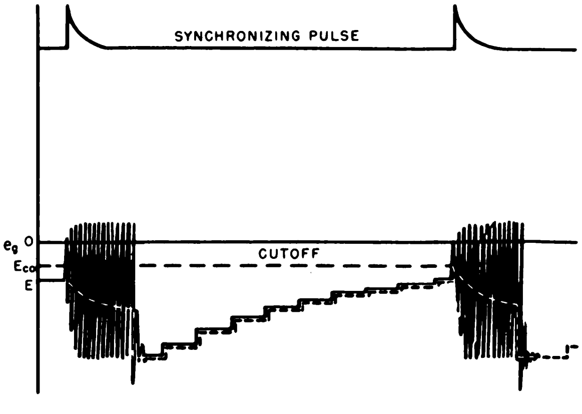

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Figure 7-24.—Grid waveshape of a line controlled, self-pulsed oscillator.

SEPARATE MODULATORS

As previously mentioned, some triode UHF oscillators are not self-pulsed, but employ separate modulators. These modulators are very much like those used with magnetron oscillators, which are discussed in chapter 9. Here, merely note that the oscillator may be plate modulated, grid modulated, or cathode modulated.

Plate Modulation

Figure 7-25 (A) shows a circuit for plate modulation in which short positive rectangular pulses applied to the grid of the modulator tube result in a negative going pulse at the plate.

Plate voltage is applied to the oscillator tube or tubes in short rectangular pulses. RF components for the oscillator are not shown in the diagram. The transformer must be specially constructed so that it passes the rectangular pulse without undue distortion. Since one purpose of the transformer is polarity inversion, the question arises as to why negative going pulses are not applied to the grid of the modulator tube to cut if off and obtain a positive going pulse at the plate for use in modulating the oscillator. This would require that the modulator tube, or tubes, conduct heavily during all the cycle except during the pulse, and would result in excessive waste of power.

The grid capacitance C_g of the oscillator is quite small, usually consisting of only the capacitance to ground of the grid tuned circuit. If made too large, C_g might cause the oscillator to be self-pulsed and cut itself off before the modulator pulse is over. C_g and R_g have values that would cause continuous wave operation if plate voltage were applied all the time. The modulator pulse is most effective in controlling the output pulse. Oscillations must build up rapidly so that the leading edge of the output pulse will be as steep as possible. The plate voltage of the oscillator must remain constant throughout the pulse.

Cathode Modulation

A cathode pulsed (modulated) oscillator does away with the necessity of inverting the pulse, hence no transformer is required. (Refer to fig. 7-25 (B).) The charging diode serves to recharge the coupling capacitor C between pulses. The capacitor must have a large capacitance, so that it will not discharge appreciably during the pulse and thereby lower the plate to cathode voltage.

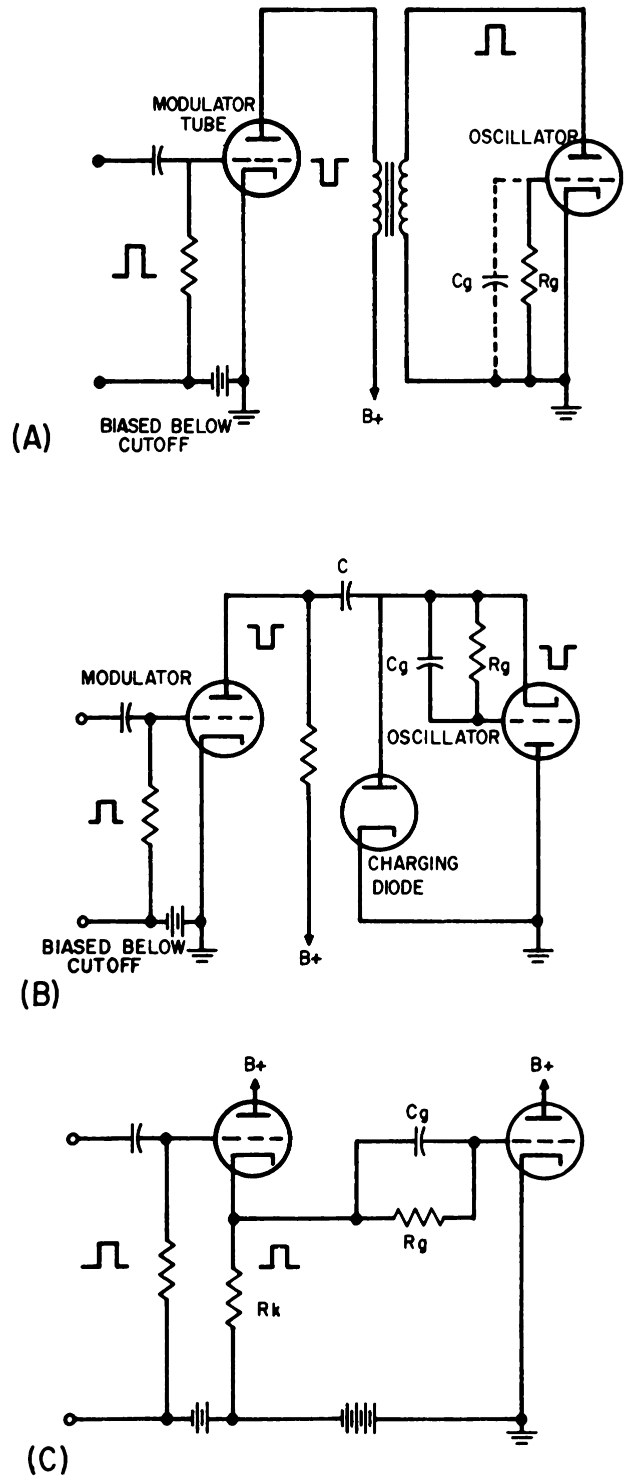

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Figure 7-25.—Pulse modulation systems.

Grid Modulation

Grid modulation requires less power from the modulator for operation than either of the other two types of modulation. A positive going rectangular pulse is applied to the grid and raises the grid voltage well above the cutoff points so that oscillation starts. Oscillation ends whenever the grid voltage drops to the normal bias. Usually the arrangement for this purpose is the one in which oscillation is started by a positive trigger pulse and ended by a self-pulsing grid bias voltage. C_g in the grid-pulsed oscillator shown in figure 7-25 (C) is a small capacitance and is used to couple the pulse from the cathode of the modulator tube to the grid of the oscillator to insure a rapid rise of voltage at the grid and cause oscillations to build up quickly.

MICROWAVE AMPLIFIERS

BASIC PARAMETRIC AMPLIFIERS

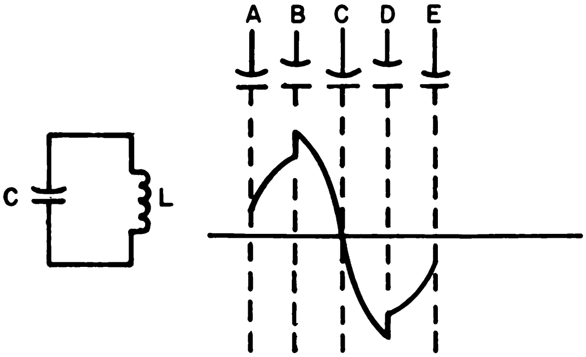
The parametric amplifier, or reactance amplifier, is a device capable of low-noise amplification in the UHF and microwave regions of the electromagnetic spectrum. Seldom has a device gone so rapidly from the laboratory into operation. The low-noise amplification afforded by these devices offers phenomenal radar range improvements on existing equipments with minimum cost and maximum economy.

The parametric amplifier increases the power level of a signal by means of the variation of an energy-storage parameter. An everyday example is that of a child on a swing. The oscillation is maintained by "pumping"; that is, the child lowers his center of gravity on the downswing and raises it on the upswing. For maximum oscillation, the pumping takes place at twice the frequency of oscillation.

Principle of Operation

The principle of operation of one form of parametric amplifier can be illustrated by an LC circuit oscillating at its resonant frequency. (See fig. 7-26).

Assume that the plates of the capacitor can be physically separated and returned to the original position. If the capacitor plates are pulled apart as shown at point B and the voltage is at maximum across the plates, then work has been expended on the capacitor since a force had to be applied to separate the plates. This work



AT. 489
Figure 7-26.—Capacitor plates varied by a pump.

appears as an increase in voltage across the capacitor since $E = \frac{q}{C}$ and the charge q remains constant while capacitance decreases. (Capacitance is inversely proportional to the thickness of the dielectric: $C = \frac{kA}{t}$.) Energy has been added to the system by the source which separated the capacitor plates. This energy transfer is referred to as pumping, and the energy source is referred to as a pump.

If the plates of the capacitor are returned to their original separation (point C) when the voltage is zero (zero charge on the plates), then no work is done and the voltage is unchanged. As the voltage passes through the maximum negative at point D, the plates are separated and voltage increases again. The frequency of the pumping source is twice the resonant frequency of the tank circuit.

Several devices may be used in parametric amplifiers to vary the capacitance or inductance electronically. One device most frequently used as a variable capacitor for microwave frequencies is the varactor diode (variable-capacitance diode). The capacitance of the varactor diode may be varied by changing the reverse bias on the diode. A discussion of varactor diodes is presented in Basic Electronics, Vol. 1, NavPers 10087-C, chapter 5.

Degenerate Mode

The simplest parametric amplifier is one which requires the pump frequency to be exactly twice the resonant frequency of the tuned circuit or signal frequency. This mode of operation is known as the degenerate mode. (See fig. 7-27 (A.)

The degenerate parametric amplifier requires a low pump frequency and power to operate, and is the least complex to design. Because it is frequency and phase sensitive, the degenerate amplifier cannot be used in most radar sets.

Nondegenerate Mode

In a practical case, the separation of the signal frequency and the pump frequency cannot be conveniently maintained constant, but will drift in and out of the optimum condition periodically, resulting in modulation of the signal frequency. Thus, the output may contain the pump frequency (f_p), signal frequency (f_s), and the pump frequency plus or minus the signal frequency. The latter is called the idler or image signal (f_i). A parametric amplifier which includes the idler circuit is called a nondegenerate amplifier. (See fig. 7-27 (B).) If the output frequency is higher than the input frequency, the amplifier is referred to as an up-converter. If the output frequency is lower than the input frequency, the amplifier is called a down-converter.

There are three basic configurations of the nondegenerate parametric amplifier which are most often used. (See fig. 7-28.) They are as follows:

1. Two-port sum-frequency (or upper side-band) up-converter.
2. Two-port difference-frequency (or lower side-band) down-converter.
3. One-port difference-frequency parametric amplifier.

In the two-port sum-frequency arrangement, the overall noise figure is higher than in other modes of operation, and the amplifier has only moderate gain. The pump frequency is less than the signal frequency, and this is important since available pump power decreases with frequency; thus, this amplifier is most useful at the highest frequencies. The name two-port comes from the fact that the output terminals are different from the input terminals. In the two-port difference-frequency mode of operation, the amplifier has a relatively narrow bandwidth, high gain, and a low-noise figure.

In the one-port difference-frequency mode, the parametric amplifier has the lowest noise figure. It is also fail-safe in that the system would continue to operate with near the same

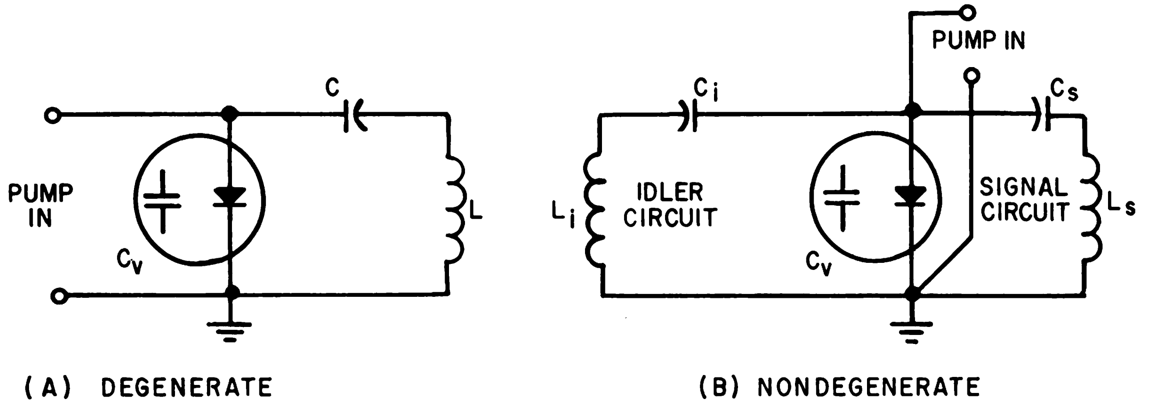


Figure 7-27.—Basic parametric amplifiers.

noise figure if the pump were to fail. However, a circulator must be used to separate the amplified output from the incoming signal; this also aids in maintaining amplifier stability because it is sensitive to source impedance changes. The operation of the one-port difference-frequency parametric amplifier for the achievement of low-noise amplification (fig. 7-29) is as follows:

The varactor D (variable-capacitance diode) must couple together all the resonant sections at three frequencies—signal, idler, and pump. For amplification to occur, the sum of the idler and signal frequencies must equal the frequency of the pump. The signal frequency must be much lower than the idler frequency to achieve low noise. However, due to the imperfect nature of the varactor, there is an upper limit for the idler frequency at which noise will increase. The capacitance of the varactor will be varied at the pump frequency rate by power from the pump. Some of this power is transferred and added to the signal when the two frequencies are mixed, resulting in power amplification. The output signal is then taken from the circulator, which separates the input and output signals.

TRAVELING WAVE PARAMETRIC AMPLIFIER

The tuned circuits used in the parametric amplifiers discussed in the previous section are usually of the coaxial or cavity type resonators. These amplifiers have a narrow bandwidth (less than 5 percent of the center frequency) because of the high Q resonators. By using a traveling wave structure and sacrificing some gain, parametric amplifiers can be designed to provide bandwidths as high as 60 percent of the center frequency. (See fig. 7-30.)

The traveling wave amplifier consists of a multistage low-pass filter which is composed of a transmission line or lumped inductances and pumped shunt varactor diodes. The filter is terminated at the desired output frequency, and this signal will not be reflected to the input. The signal and pump frequencies are injected at one end of the traveling wave structure and the desired output taken at the opposite end.

The signal, pump, and idler frequencies are within the bandpass of the filter and the sum of the pump and signal frequencies are outside the bandpass. As the wave travels down the line, the idler and signal voltages increase as energy is transferred from the pump. Although gain increases as the length of the traveling wave structure is increased, the resistive losses also increase. There is an optimum length of line for maximum gain. The main disadvantage of the traveling wave parametric amplifier is that it has a lower gain than the narrowband amplifier.

UHF RECEIVER INPUT CIRCUITS

Proper selection of the input circuits to UHF and microwave receivers is a design consideration. Proper functioning of these circuits is an

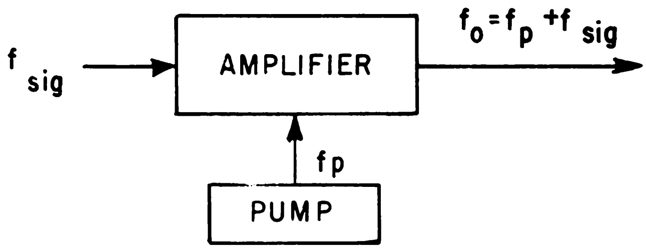
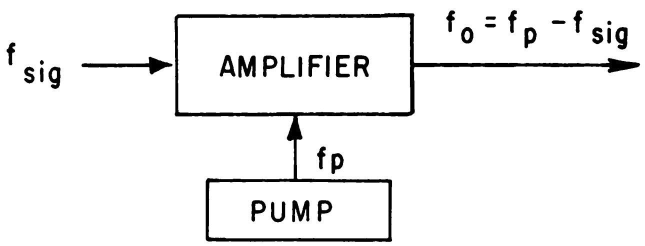
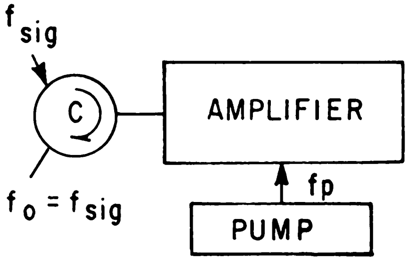
PARAMETRIC-AMPLIFIER MODE	CONFIGURATION
2-PORT SUM-FREQUENCY (or upper sideband) Up-converter.	 f_{sig} AMPLIFIER $f_o = f_p + f_{sig}$ fp PUMP
2-PORT DIFFERENCE FREQUENCY (or lower sideband) Down-converter.	 f_{sig} AMPLIFIER $f_o = f_p - f_{sig}$ fp PUMP
1-PORT DIFFERENCE-FREQUENCY	 f_{sig} C AMPLIFIER fp PUMP $f_o = f_{sig}$

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Figure 7-28.—Basic configuration of the parametric amplifier.

important operating and maintenance consideration. An understanding of the characteristics, limitations, advantages, and disadvantages of the various types of input circuits is quite helpful for proper analysis and maintenance of the circuit and the set.

The input circuit determines receiver sensitivity. If gain were the only consideration, the receiver could be made to respond to even the smallest signal by merely adding stages of amplification. However, every amplifier (in fact, every electronic circuit) introduces noise into the overall signal. Since the input signal to the receiver is usually the smallest signal to be found anywhere in the receiver, the noise characteristics of the input circuit are of the utmost importance.

NOISE IN RECEIVERS

There are many types of noise generated outside the receiver. These types enter the receiver along with the desired signal, and may possibly be eliminated by means of the selectivity of the set. Outside radio noise interference is discussed in chapter 4 of this manual. Noise generated within the receiver, the sources, and the methods of prevention or elimination are discussed in Basic Electronics, NavPers 10087-C, Vol. 2, chapter 5.

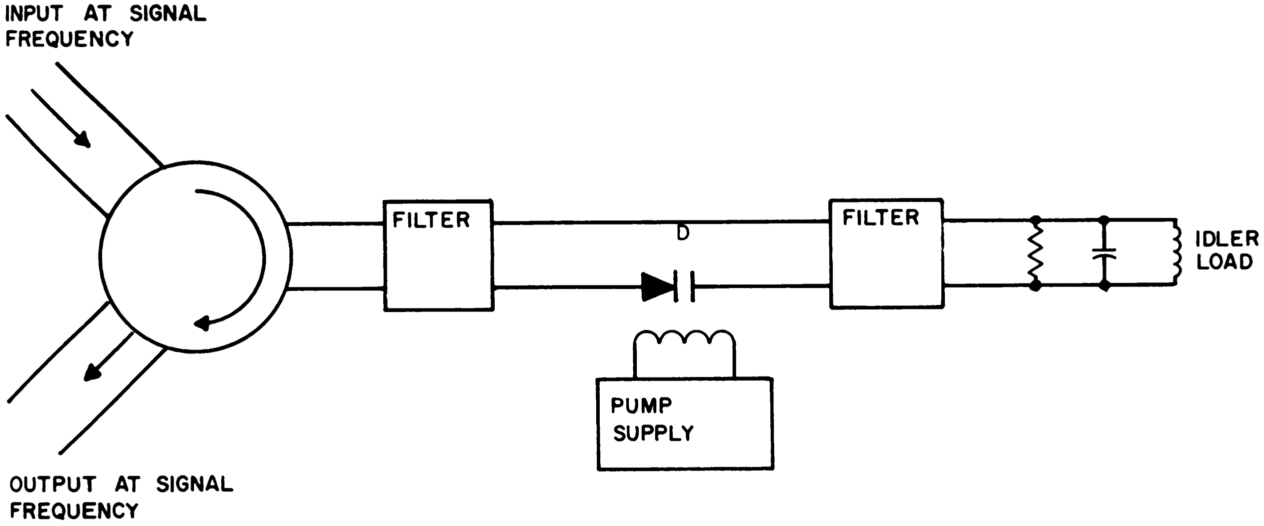

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Figure 7-29.—One-port difference-frequency parametric amplifier.

The NOISE FIGURE (or NOISE FACTOR) of a receiver is calculated by dividing its input signal to noise ratio by its output signal to noise ratio. Since the noise varies with temperature, the noise figure is usually expressed at a standard temperature of 63° F. The noise figure is expressed sometimes in decibels, and sometimes as a number. The smaller the number, the better the receiver.

Amplifiers connected in cascade will normally have a higher total noise figure than any of the individual amplifiers. The noise generated in the first stage will be introduced into the second, and amplified along with the desired signal. In addition, the second stage will generate noise of its own, to be further amplified by succeeding stages. Therefore the second stage also should have a low noise figure,

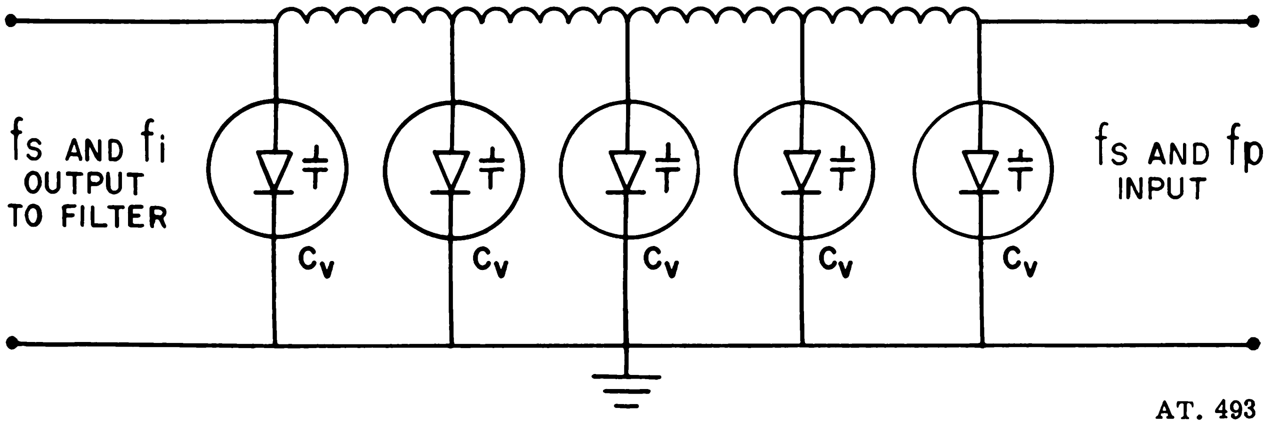

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Figure 7-30.—Traveling wave parametric amplifier.

although the noise figure of the first stage is the prime determining factor in receiver sensitivity.

LOW NOISE RF AMPLIFIERS

Conventional design of superheterodyne receivers calls for an RF amplifier as the input stage preceding the mixer stage. Due to the noise considerations just discussed, however, the use of the preamplifier at the microwave frequencies has been found impractical. It has been common practice to use the mixer as the input stage, with no RF amplifier preceding it. Recent developments in low noise devices, however, permit use of amplifiers based on these devices as input stages for microwave receivers. The devices discussed in this section are the traveling wave tube and backward wave amplifiers. Basic operation of traveling wave tubes and backward wave amplifiers has been covered earlier in this chapter. The low noise properties of these devices are obtained by the use of a specially designed electron gun. When the TWT is used as an input amplifier, a filter is normally employed to reject the image frequency. Without the filter, if the image frequency is allowed to pass, the noise power is doubled; but with the filter, the usable output power is slightly reduced as a result of filter losses. Generally no filter is required for narrowband amplifiers such as the backward wave amplifier because the bandwidth is less than the IF frequency and the image is adequately rejected. Other UHF and microwave RF amplifiers are discussed in Basic Electronics, NavPers 10087-C, Vol. 2.

MIXERS

The purpose of the mixer in a superheterodyne receiver is to combine the frequency of the incoming signal with the frequency of the local oscillator, and to produce from these two a third frequency (the difference between them, usually) known as the INTERMEDIATE FREQUENCY (IF). The IF is normally much lower than either of the other two frequencies. The IF is amplified and used to carry the impressed intelligence of the incoming signal through the remainder of the RF circuits.

The basic principles of superheterodyne receivers, UHF communications, and microwave receivers are discussed in Basic Electronics, NavPers 10087-C, Volumes 1 and 2. The objective of this section is to present a more detailed discussion of mixers used in UHF and microwave equipment.

INPUT SIGNALS

For operation of the mixer, it is necessary to provide two signals at slightly different frequencies. The first of these frequencies is the incoming signal, with its intelligence impressed upon it. This signal is picked up from the air in the form of electromagnetic waves, and is converted in the antenna circuits into electrical currents and voltages. From the antenna, this signal is carried to the mixer through some form of transmission line (usually coaxial cable or waveguide), possibly (but not necessarily) through an amplifier.

The second required frequency is produced by the local oscillator. The local oscillator may be a klystron, magnetron, backward wave oscillator, or any other type oscillator capable of producing a small amount of energy at the desired frequency.

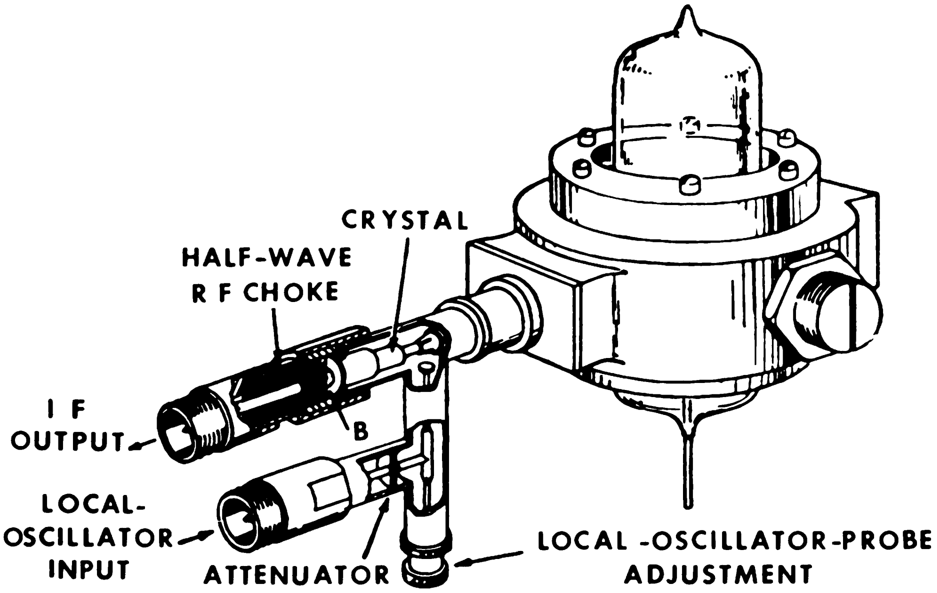
SINGLE-ENDED CRYSTAL MIXERS

Because crystals are delicate, they must be protected extremely well by the TR device in order to avoid burnout during transmission. Vacuum tubes, on the other hand, are able to withstand relatively large amounts of transmitter power. Mixer circuits employing triodes have a somewhat higher conversion gain than crystal mixers, although they generate more noise. The effect of the increased noise may be offset at ultrahigh frequencies by preceding the triode mixer by one or more stages of radiofrequency amplification—the noise figure of a triode is appreciably less when used as an amplifier than when used as a mixer.

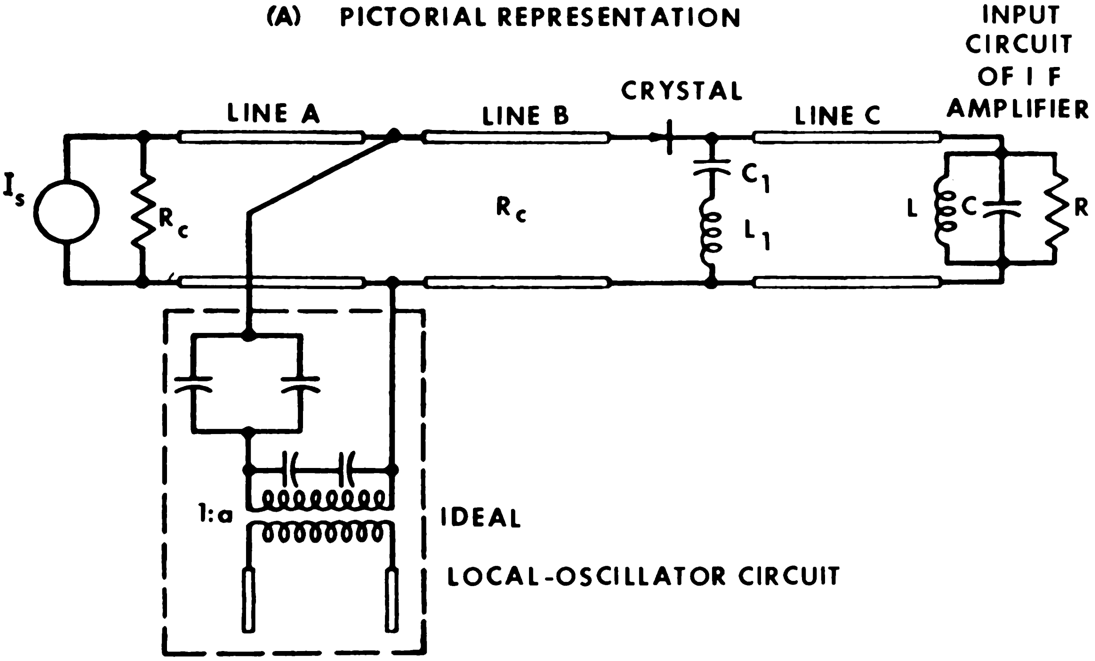
Unfortunately, most tubes that are available for operation in the microwave region generate an excessive amount of noise and are therefore not suitable for the input circuits of microwave receivers. Consequently, use of vacuum tube input circuits is usually restricted to receivers that operate in and below the UHF range.

Echo signals of a microwave radar system, after passing through the TR device, are applied to the crystal mixer. A voltage from a local oscillator is applied to the mixer simultaneously with the echo signals, and signals at the intermediate frequency are derived at the mixer output terminals.

The important features of a 10-cm mixer employing coaxial line sections are given in figure 7-31 (A).



(A) PICTORIAL REPRESENTATION



(B) AN EQUIVALENT CIRCUIT

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Figure 7-31.—A 10-cm mixer.

Echo signals are coupled into the transmission line section between TR cavity and crystal by means of a coupling loop which penetrates a short distance into the cavity. The crystal fits snugly into the inner conductor of the line and is held concentric with the outer conductor by means of a dielectric bead. The local oscillator signal is introduced into the mixer assembly by means of a coupling probe located approximately a quarter wave (at the local oscillator frequency) from the coupling loop in the TR cavity. A high impedance in the direction of the cavity is thus presented to the local oscillator signal at the probe. The strength of the local oscillator signal at the crystal may be changed by varying the distance the probe extends into the main line. Power from the local oscillator is conducted to the probe via a section of transmission line.

Connection between the crystal and inner conductor of the line section carrying IF signals is provided by a spring contact (fig. 7-31 (A)). The half-wave RF choke appearing on the IF side of the crystal provides an electrical short circuit for radio frequency signals at point B. The d-c return path required for crystal current is provided at the RF end of the mixer assembly by the TR coupling loop and at the IF end by the shunt inductance element located in the grid circuit of the input IF amplifier stage.

A two-wire equivalent circuit of the mixer is given in figure 7-31 (B). If small losses in the RF line and TR cavity are ignored, the portion of the RF transmission system between antenna and output terminals of the TR cavity may be represented by a signal current source I_S in shunt with the characteristic resistance R_C of the transmission line. Because the local oscillator is loosely coupled to the main line, negligible admittance appears in shunt with the lines A and B in figure 7-31 (B). Elements L1 and C1 represent the RF choke at the IF end of the crystal and are series resonant at the echo signal frequency. Hence line B is terminated by the crystal at the echo signal frequency. For maximum receiver sensitivity it is important that essentially all the echo power available at the TR device be transferred to the crystal. The crystal should therefore present a matched load termination to the main line section. Fortunately 10-cm crystal units, when operated with 5/16-inch 50-ohm coaxial lines, provide essentially a matched RF load for the line. An impedance changing device between crystal and TR cavity is therefore unnecessary.

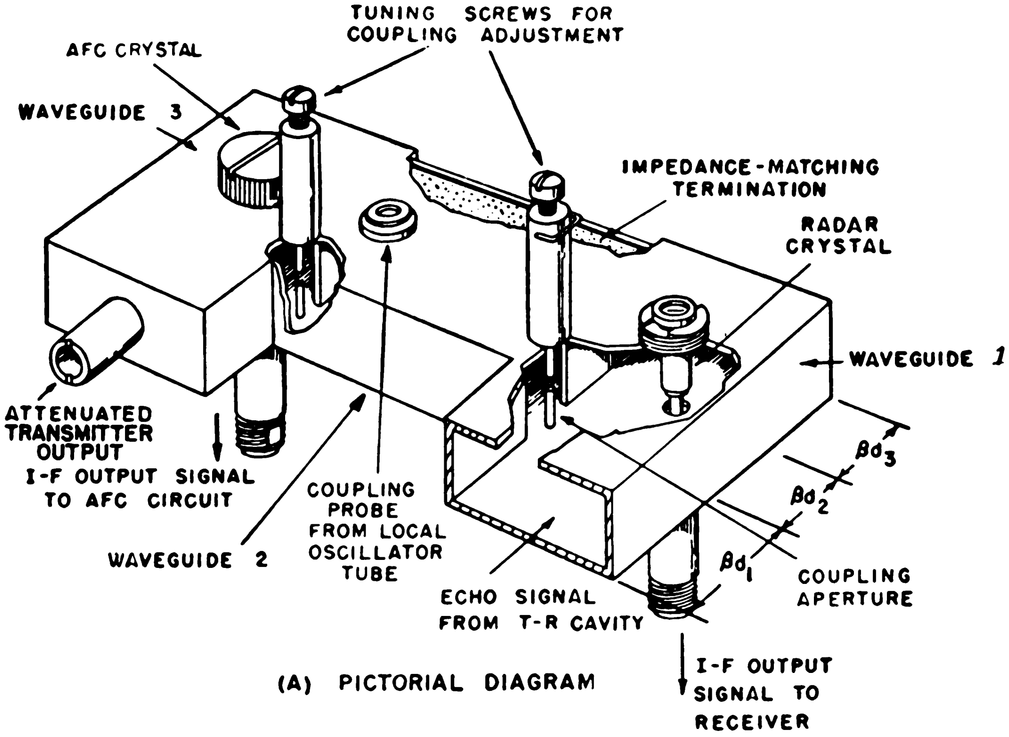
Because the local oscillator is loosely coupled to the main line containing the crystal, an appreciable mismatch of impedance exists on the local oscillator line at the coupling probe. A large impedance mismatch is in general undesirable because of the wide variations in local oscillator load impedance (and hence power output) that result when the oscillator frequency is varied. A good impedance match is particularly important if the line between local oscillator and probe is long. To insure a relatively constant load impedance for the oscillator, a resistance disk type of attenuator is often inserted in the local oscillator line, as shown in (A), in order to terminate the line section between oscillator and disk in its characteristic resistance. An alternative to the resistance disk is a piece of lossy cable which may be inserted between local oscillator and mixer assembly. (NOTE: Lossy cable uses resistance wire for the center conductor. An example of lossy cable is RG-21/U.)

Oftentimes mixer assemblies include, in addition to the circuit that supplies IF echo signals, a separate mixer for generating IF signals for the automatic frequency control circuit. An example of a 3-cm mixer assembly of this type is shown in figure 7-32 (A).

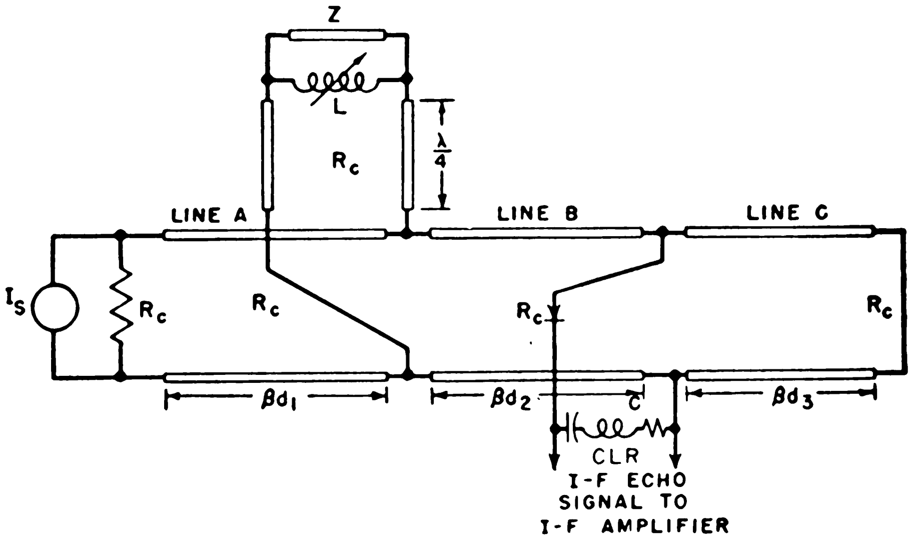
Local oscillator power and RF echo signals from the TR cavity are coupled into waveguide 1, which serves as the echo signal channel. A crystal extends between top and bottom walls of the guide, the lower end of the crystal being isolated from the guide by means of a dielectric washer. Echo signal voltages in the intermediate frequency band appear between the lower end of the crystal and the waveguide and are conducted to the input circuit of the IF amplifier, usually over a coaxial cable.

Waveguide 3 is similar in construction to waveguide 1 and serves as the AFC channel. Power from the local oscillator and a small amount of the transmitter power are applied to the AFC crystal, and IF signals for the AFC circuit are derived at the lower end of the crystal mount, as before. Attenuation between the main guide and guide 3 is provided by means of a circular waveguide section operating below cutoff. Sometimes a disk type attenuator is included in the circular section to reduce further the amount of transmitter power reaching the mixer assembly.

The local oscillator tube is mounted above waveguide 2 in a manner that permits the local oscillator output probe to extend a short distance into guide 2. The coupling probe may be


TUNING SCREWS FOR COUPLING ADJUSTMENT
AFC CRYSTAL
WAVEGUIDE 3
IMPEDANCE-MATCHING TERMINATION
RADAR CRYSTAL
WAVEGUIDE 1
ATTENUATED TRANSMITTER OUTPUT
I-F OUTPUT SIGNAL TO AFC CIRCUIT
WAVEGUIDE 2
COUPLING PROBE FROM LOCAL OSCILLATOR TUBE
ECHO SIGNAL FROM T-R CAVITY
βd3
βd2
βd1
COUPLING APERTURE
I-F OUTPUT SIGNAL TO RECEIVER

(A) PICTORIAL DIAGRAM



(B) AN R-F EQUIVALENT CIRCUIT OF ECHO-SIGNAL CHANNEL

AT.221

Figure 7-32.–A 3-cm mixer.

isplaced slightly from the center of the trans- erse axis of the guide in order to obtain a load npedance for the oscillator which yields a easonably uniform power output over the tuning ange.

Local oscillator power is coupled from guide into guides 1 and 3 through coupling apertures ocated in the side walls of the guides. A match- ng post and tuning screw extending from top nd bottom walls of the guides at the aperture ocations serve to regulate the amount of local scillator power coupled to the mixer circuits.

For optimum performance of the radar sys- em, the echo signal channel of the mixer hould provide a matched load impedance to the aveguide transmission system. The elements hat determine the mixer input impedance are hown in the equivalent circuit (B). The equiva- ent circuit is derived by dividing waveguide 1 nto three sections of lengths Bd_1, Bd_2, and Bd_3 nd representing the sections by equivalent engths of transmission lines (lines A, B, and in fig. 7-32 (B)). The signal current generator s in shunt with R_C in the equivalent circuit ccounts for the portion of the RF system etween antenna and mixer. The coupling perature between local oscillator and mixer uides (guides 1 and 2) is represented by a ariable inductance L, and in shunt with L is an npedance Z which accounts for the impedance een in the direction of the local oscillator guide. he parallel combination of L and Z terminates quarter-wave section of line which is in shunt ith lines A and B. At the echo signal frequency, e impedance L and Z in parallel is maintained mall enough in comparison with the charac- eristic resistance of the quarter-wave line to ake the imput impedance of the quarter-wave ection extremely high and hence the amount of cho signal power entering the local oscillator uide is extremely small.

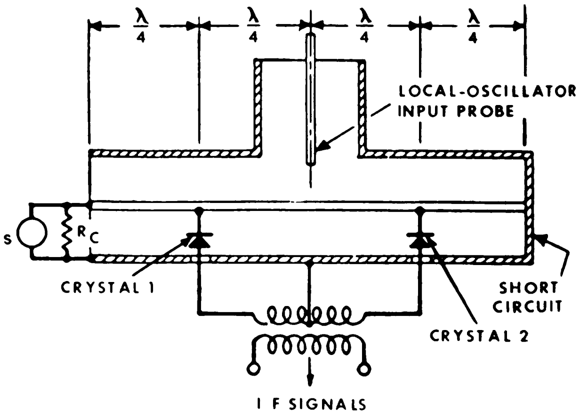
The crystal is located at the junction of lines and C, as shown in figure 7-32 (B), and across e crystal output terminals is a series RLC ircuit. The counterpart of the RLC combination s an RF choke in the IF output lead of the mixer. he choke prevents RF signals from entering the nput circuit of the IF amplifier.

The length of shorted-end line C must be uch that the input admittance of line C, in shunt ith the RF admittance of the crystal, provides ssentially a matched load for line B. Varying e length of line C changes the susceptance omponent of the total admittance at the crystal ocation. A length of approximately λ/4 is usually preferable in order to minimize changes in admittance with frequency.

BALANCED MIXERS

The noise introduced into the input circuit of a microwave receiver by the local oscillator may be reduced appreciably through use of a balanced mixer. An input circuit of this type employs two crystal mixers connected so that the local oscillator voltages applied to each crystal are in phase and the echo signal voltages at each crystal are 180° apart in phase. As explained below, this method of circuit connection causes the IF components of local oscillator noise to cancel in the IF amplifier input circuit and the IF components of the signal to add. Because of their ability to suppress local oscillator noise and because of certain additional advantages to be discussed later, balanced mixers are often preferable to single-ended mixers. They are presently finding wide use in microwave radar systems.

The basic principles of a balanced mixer may be explained from the diagram of figure 7-33, which shows two crystals mounted a half wavelength apart (at the signal frequency) between conductors of a coaxial line section. Each crystal is located a quarter wave from the nearer end of the line, and the local oscillator signal is probe coupled to the line at a point midway between the crystals. The output



AT.222

Figure 7-33.–Coaxial line balanced mixer circuit.

terminals of the crystals are connected to an IF transformer, the primary winding of which is balanced to ground. The signal current generator I_S in shunt with resistance R_C accounts for signals entering the mixer from the TR device.

The local oscillator coupling probe gives rise to two waves traveling in opposite directions in the coaxial line. Assume that at the local oscillator frequency the TR device presents a short circuit to the local oscillator wave traveling to the left in figure 7-33, and that the crystals have identical RF impedances equal to twice the characteristic resistance of the line. Then equal-amplitude, in-phase, local oscillator voltages appear at the crystals. Because of the half-wave spacing between crystals, the RF echo signal voltages at the crystals are also of equal amplitude but are 180° apart in phase. An in-phase relation between local oscillator and echo signal voltages produces an IF signal voltage of one phase, and a 180° phase relation between local oscillator and echo signal produces an IF signal voltage of opposite phase. Thus the two IF echo signal voltages add in the balanced input circuit of the IF amplifier. Because the noise that accompanies the local oscillator signal produces voltage components that bear the same phase relation to the local oscillator voltage at each crystal, the corresponding IF components of noise at the output of each crystal are in phase and hence produce no resultant noise voltage across the IF transformer.

In order to realize full benefit from use of a balanced mixer circuit, the crystals should have similar RF impedances as assumed above, and in addition they should have similar conversion gains. Under these conditions of operation, only one-half the available RF power is applied to each crystal, but since the IF signal powers from the crystals add together, the total IF power is the same as that obtained from a single-ended mixer. Since IF components of local oscillator noise are completely eliminated, maximum reduction in overall noise figure is obtained.

An imbalance in conversion gain yields an imbalance in the IF signal voltages obtained from each crystal and also an imbalance in the IF components of local oscillator noise voltages at the crystal output terminals. However, since the IF signal voltages are additive in the crystal output circuit and the local oscillator noise components are subtractive, small imbalances in conversion gains do not seriously affect the overall receiver noise figure.

More important are the effects of a difference in the RF admittances of the crystals. An imbalance of this type causes both the echo signal power and the local oscillator power to divide unequally between the two crystals. As a result, the IF signal power obtained from the mixer is appreciably reduced, and in addition the IF components of local oscillator noise are prevented from canceling completely in the IF input circuit. Crystals intended for use in a mixer constructed as shown in figure 7-33 must be carefully selected on the basis of equal RF admittances in order to insure most satisfactory operation.

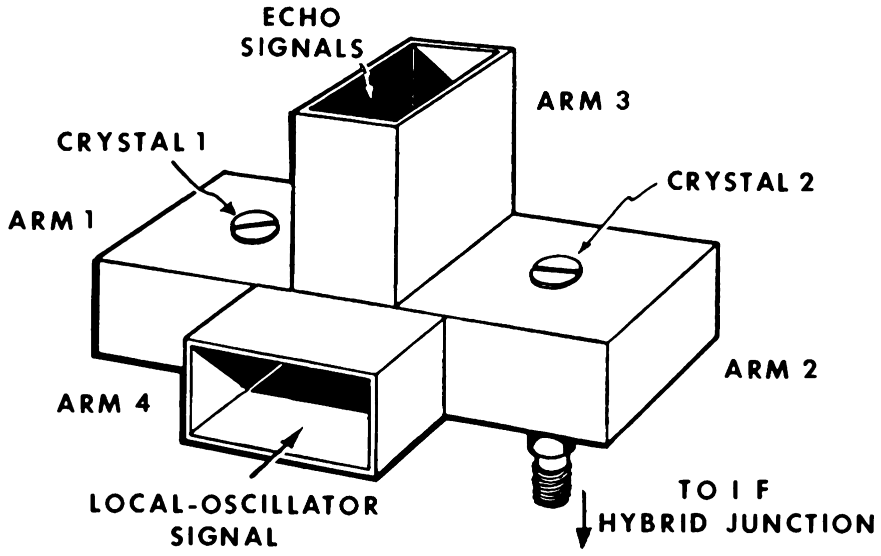
A balanced mixer that is superior in several respects to the coaxial line mixer just described is shown in figure 7-34 (A). This mixer employs a waveguide hybrid junction.

Crystals are located in one pair of entries (arms 3 and 4). Usually in a mixer of this type the input circuit of the IF amplifier is also arranged in the form of a hybrid junction.

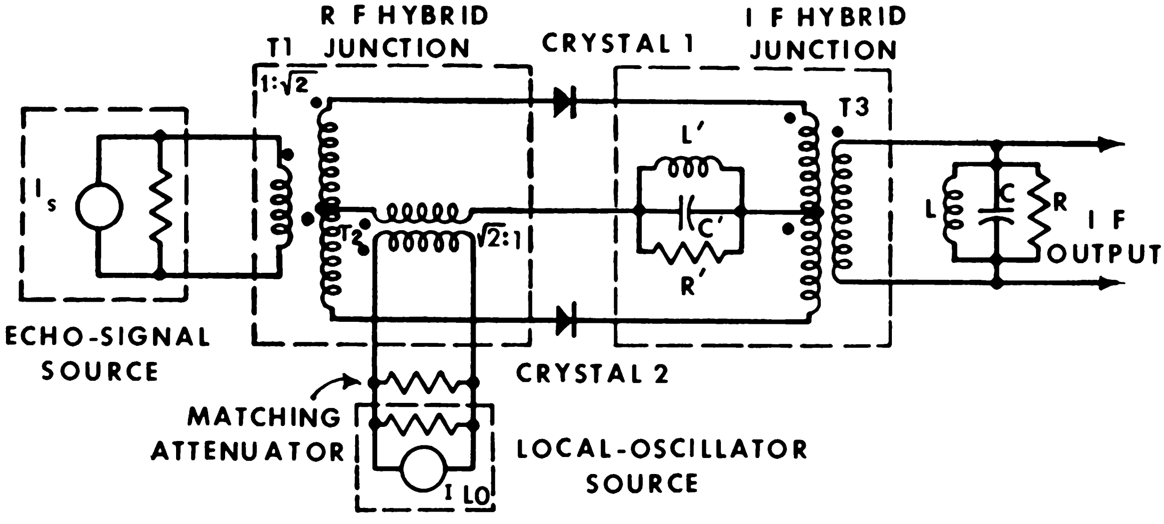
Details of connections of the IF amplifier input circuit, together with the ideal transformer equivalent circuit of the waveguide junction are given in the right-hand block of (B). The parallel circuit comprising L, C, and R is tuned to the intermediate frequency and the impedance of the parallel combination of L', C', and R' is made equal to the conjugate of the IF impedance appearing between the terminals to which L', C', and R' are connected.

Ideally the two crystals should be alike. Furthermore, all RF impedances should terminate the entries of the RF hybrid junction in matched loads, and all IF impedances should similarly terminate the entries of the IF hybrid junction. Then, because of the properties of a matched hybrid junction, local oscillator signals at the crystals are equal in amplitude and in phase, and echo signals at the crystals are equal amplitude and 180° apart in phase.

The IF components of signals from the crystals are applied in push-pull to ideal transformer T3 and appear across L, C, and R but not across L', C', and R'. The IF components of noise, on the other hand, are in effect applied between end terminals of T3 in parallel and appear across L', C', and R', but not across the IF output terminals. Local oscillator noise is thus suppressed completely. Because the RF hybrid junction is matched, the total available power from the echo signal and local oscillator



(A) PICTORIAL DIAGRAM



(B) EQUIVALENT CIRCUIT

AT.494

Figure 7-34.—Balanced mixer employing hybrid junctions.

arms divides equally between the two crystals. As in the coaxial line mixer of figure 7-33, the IF power from each crystal is one-half the available echo signal power times the conversion gain G of the crystal. Since IF power from each crystal is delivered at the IF output terminal, the total IF output is the product of the echo signal power and G, as before.

Ordinarily, in single-ended mixers and in the coaxial line balanced mixer (fig. 7-33), the local oscillator must be loosely coupled to the mixer in order to prevent an appreciable amount of echo signal power from entering the local oscillator circuit. As a result, the local oscillator must generate much more power than is actually needed for mixer operation, the excess power being dissipated in an impedance changing device located in the local oscillator circuit. Because in a hybrid junction mixer the echo signal and local oscillator arms are decoupled, there is no tendency for echo signals to enter the local oscillator circuit, and hence there is no need for loose coupling between local oscillator and mixer. A local oscillator with relatively low power output can therefore be used, the only power necessary being that which is needed to drive the crystals. Actually most local oscillators are capable of generating more than the minimum power required, so that a dissipative attenuator can be inserted in the local oscillator in order to insure a matched termination for the arm. Such an attenuator is desirable, as will be seen later.

Decoupling between echo signal and local oscillator arms also means that there is no tendency for local oscillator power to enter the echo signal arm. Rejection of local oscillator signal by the echo signal arm is particularly advantageous in systems employing a broadband TR device which would allow local oscillator power to pass through and be radiated by the antenna.

Another advantage of the hybrid junction mixer is that its operation is less sensitive to differences in the RF impedance of the crystals than is the balanced coaxial line mixer. Because the two crystal arms are decoupled, any RF power reflected from one crystal cannot reach the other crystal. All the reflected power is directed into the echo signal and local oscillator arms and absorbed by the matched terminations. Thus the amount of RF power delivered to one crystal is independent of the RF impedance to the other.

If a mismatch should exist in either the echo signal or local oscillator arm, a reflection of an RF signal arriving at the mismatched termination will occur, and the signal reflected from the termination will enter the two crystal arms. Under these circumstances, the two crystal arms are not completely decoupled. At the echo signal frequency a mismatch in the echo signal and local oscillator arms is unlikely because in general the TR device provides a matched load for the echo signal arm and, as indicated above, a matching attenautor can normally be inserted in the local oscillator arm.

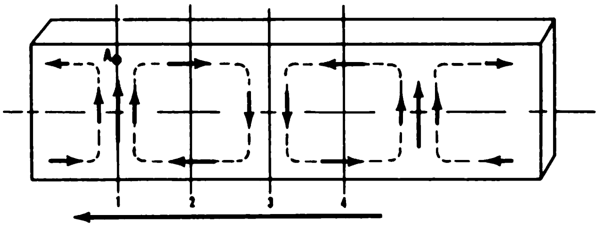
In general, if the crystals provide an impendance match at the echo signal frequency, they do not yield a perfect match at the local oscillator frequency. This mismatch is unimportant, since the reflected power will be absorbed in the echo signal and local oscillator arms. The attenuator in the latter arm serves to prevent the returned signal from reacting on the oscillator. Should the echo signal arm not provide a matched termination for the returned local oscillator signal, further reflection of the signal will occur and the balance of local oscillator power at the crystals will be further upset. The effect of such an imbalance is to change the conversion gains of the crystals slightly, but usually the change is negligible even with moderate amounts of mismatch at the local oscillator frequency.

Use of the hybrid junction type of IF input circuit shown in figure 7-34 (B) insures suppression of local oscillator noise despite imbalance in the IF impedances of the crystals. When all entries of the IF hybrid junction are terminated in a load that is the conjugate of the impedance faced by the load, the two crystals (constituting one pair of entries) are decoupled and the two resonant circuits (constituing the other pair) are also decoupled. If the resonant load entries remain matched, the amount of IF signal power coupled from one crystal to the output terminals is independent even if the IF impedance of the other crystal does not match the arms. Furthermore, the IF components of noise cancel in the output circuit independently of the IF crystal impedance as long as the crystals develop equal IF noise voltage. The IF components of noise appear only across the L', C', and R' arm. If crystals are tested for equal conversion gains while loaded by the conjugate of the IF impedance of a typical crystal, equal IF noise voltages can be expected when the crystals are employed in the circuit.

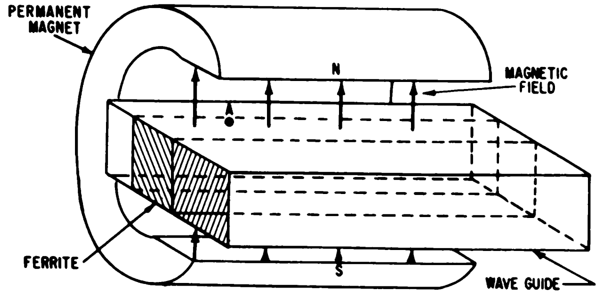
Terminating the IF output entry in a matched load does not in general insure minimum noise figure. Mismatching the output entry in order to minimize the noise figure alters the load the push-pull IF echo signals and thus reduces the echo signal power delivered to the load but does not alter the load for the IF components of noise which are applied to T3 in parallel. The local oscillator noise suppression property of the mixer is therefore retained.

MICROWAVE FERRITES

The most common ferromagnetic substances (iron, nickel, cobalt, and their alloys) are good electrical conductors. They cannot, therefore, be used as magnetic materials at the higher frequencies because of eddy current losses. Ferrites, however, are not subject to eddy currents. Even though their magnetic susceptibility is much lower than that of the ordinary ferromagnetic substances, they can be used at the higher frequencies. Ferrites are unique because they have useful magnetic properties and are also insulators. RF fields can penetrate a ferrite; this is not possible in a conducting magnetic substance.



(A) MAGNETIC FIELD ROTATION



(B) RESONANCE ISOLATOR

AT.223

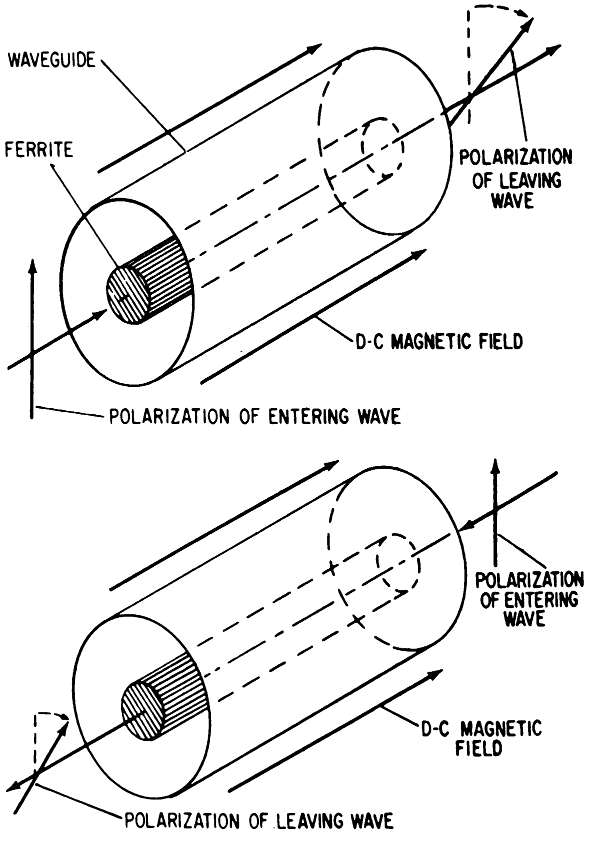
Figure 7-35.—Ferromagnetic resonance.

At microwave frequencies, the greatest use of ferrites is in nonreciprocal propagation devices. Nonreciprocal devices can be used to isolate a signal source from its load. A magnetron or other microwave signal source operating into a varying mismatched load (as in the case of a scanning antenna which is fed by a line with rotating joints;) tends to "pull" in frequency. If the reflected energy caused by mismatch is absorbed or diverted before it reaches the source, the source will "see" a constant load.

Nonreciprocal ferrite devices make use of the interaction of the electron's spin with an external magnetic field.

Ferromagnetic Resonance

When a ferrite is placed in an external magnetic field, the "atomic" magnets within the ferrite tend to line up with the external field.


WAVEGUIDE
FERRITE
POLARIZATION OF LEAVING WAVE
D-C MAGNETIC FIELD
POLARIZATION OF ENTERING WAVE
POLARIZATION OF ENTERING WAVE
D-C MAGNETIC FIELD
POLARIZATION OF LEAVING WAVE

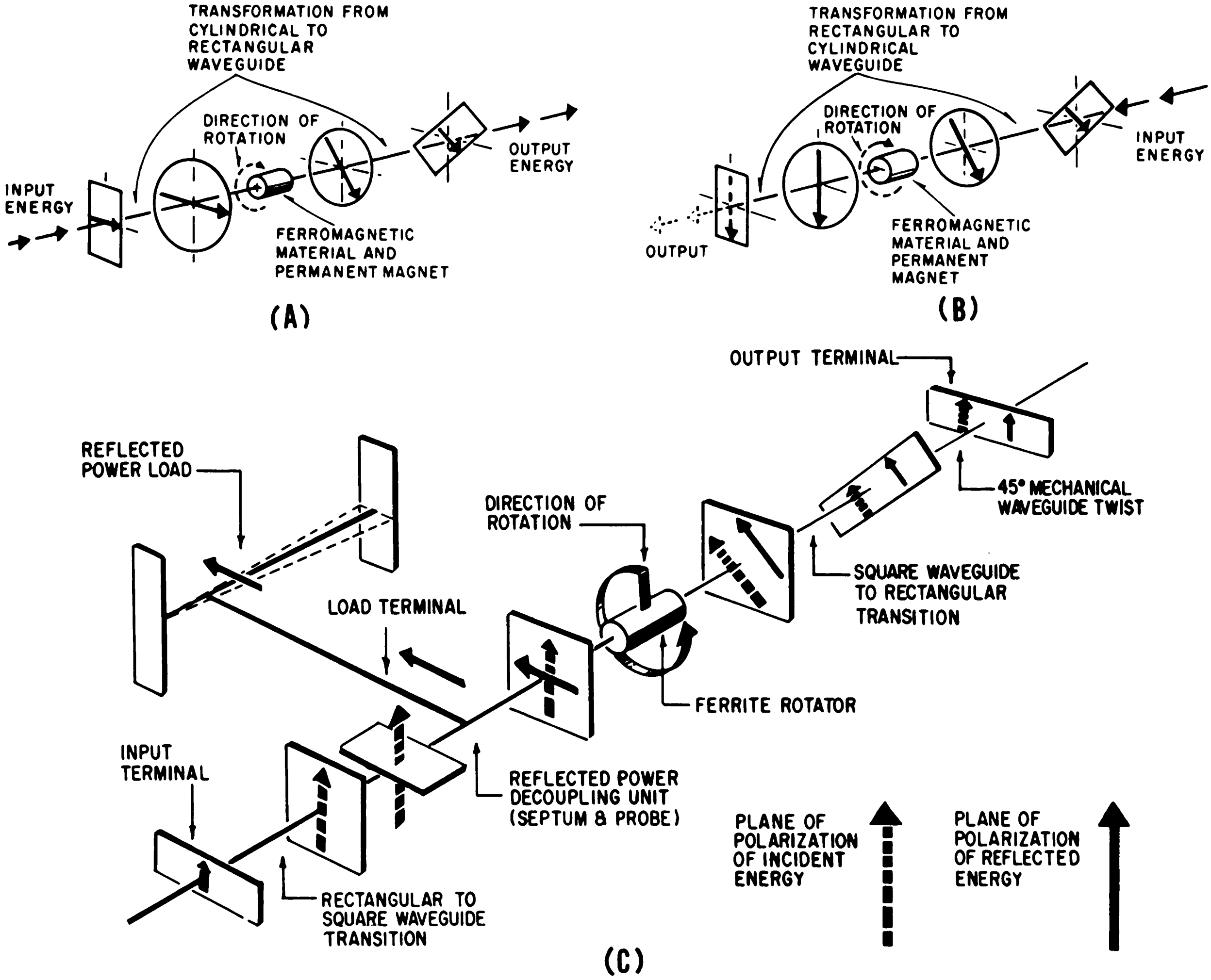
AT.244

7-36.—Faraday rotation.

A spinning electron has gyroscopic properties. When an external force attempts to change the spin axis, the electron precesses. Any gyro has a preferred or natural precession frequency which is proportional to the strength of the external field. By proper choice of ferrite material and external field strength, the natural precession frequency can be made to coincide with any selected microwave frequency.

An electromagnetic wave traveling down a waveguide will produce, at a point off the centerline of the guide, a rotating magnetic field. This is illustrated in figure 7-35 (A). As the wave advances from right to left, the stationary point A sees a clockwise rotating magnetic field. A wave traveling from left to right will produce, at point A, a magnetic field with counterclockwise rotation.

A slab of ferrite placed off center in a waveguide, as shown in (B), will act as a one-way device at a frequency which depends on the external magnetic field strength. If the ferrite's


TRANSFORMATION FROM CYLINDRICAL TO RECTANGULAR WAVEGUIDE
DIRECTION OF ROTATION
OUTPUT ENERGY
INPUT ENERGY
FERROMAGNETIC MATERIAL AND PERMANENT MAGNET
(A)
TRANSFORMATION FROM RECTANGULAR TO CYLINDRICAL WAVEGUIDE
DIRECTION OF ROTATION
INPUT ENERGY
OUTPUT
FERROMAGNETIC MATERIAL AND PERMANENT MAGNET
(B)
OUTPUT TERMINAL
REFLECTED POWER LOAD
45° MECHANICAL WAVEGUIDE TWIST
DIRECTION OF ROTATION
SQUARE WAVEGUIDE TO RECTANGULAR TRANSITION
LOAD TERMINAL
FERRITE ROTATOR
INPUT TERMINAL
REFLECTED POWER DECOUPLING UNIT (SEPTUM & PROBE)
PLANE OF POLARIZATION OF INCIDENT ENERGY
PLANE OF POLARIZATION OF REFLECTED ENERGY
RECTANGULAR TO SQUARE WAVEGUIDE TRANSITION
(C)

AT.225

Figure 7-37.—Faraday isolators.

preferred electron precession frequency matches the frequency of an RF wave traveling from left to right in the guide, the ferrite will absorb most of the energy in the wave; the rotating magnetic field as seen at point A will aid electron precession. The electrons will precess vigorously and convert the RF energy to heat. This phenomenon is known as ferromagnetic resonance. A wave traveling from right to left will be attenuated very little because its rotating magnetic field will oppose electron precession. The one way device shown is a RESONANCE ISOLATOR.

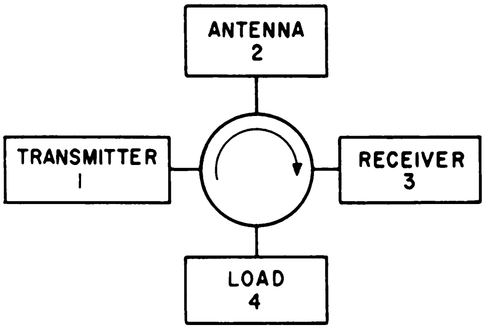
Faraday Rotation

If a plane-polarized wave is propagated through a circular (or square) waveguide containing an axially mounted ferrite rod, the plane of polarization will be rotated when a magnetic field is applied parallel to the direction of propagation. The amount of rotation will depend on the strength of the applied field and the dimensions of the ferrite rod. The sense or direction fo rotation will depend only on the polarity of the magnetic field. Figure 7-36 illustrates Faraday rotation.

Faraday rotation occurs as the wave travels past the ferrite rod. The plane of rotation is shifted in the same direction, regardless of the direction of wave propagation, as can be seen by comparing (A) and (B) of the figure.

An isolator which uses the Faraday effect is shown in figure 7-37 (A) and (B). A plane-polarized wave comes down the guide and goes through a rectangular-to-round waveguide transition. As the wave passes the ferrite in (A), its plane of polarization is rotated 45° clockwise, and it leaves through the rectangular guide. If a wave comes down the guide in the reverse direction, it will also be rotated 45° clockwise (as viewed from the left) as shown in (B). The wave will be 90 ° from the transmission plane of the rectangular guide (the guide will be cut off for this polarization), and the wave will be reflected. Properly oriented vane type absorbers will absorb this energy without affecting waves traveling in the other direction.

In isolators designed to handle high power, the reflected wave can be coupled out to a separate power-absorbing load. An isolator of this type is shown in figure 7-37 (C).



AT. 226

Figure 7-38.—Circulator.

SWITCHES

A Faraday isolator can be modified to act as a single pole, double throw, WAVEGUIDE SWITCH. In the waveguide switch, the output end of the device has two rectangular output guides 90° apart. Each output guide is 45° from the input guide at the other end of the device. An electromagnet supplies the external field. Switching is accomplished by reversing the direction of current flow in the electromagnet. Current in one direction causes the RF wave polarization to be rotated clockwise 45°. Electromagnetic current in the opposite direction causes the wave polarization to rotate 45° counterclockwise. In each case, only one of the otuput guides will accept the RF wave. Switching times of less than 1 μsec are possible. Isolation between the output guides (if they are properly terminated) is on the order of 40 db. This type of switch can be used to switch a transmitter between two antennas.

Circulators

A CIRCULATOR is a device which allows one-way propagation of signals through it. It may have several input-output ports. Figure 7-38 is a schematic of a four-port circulator. The arrow shows direction of power flow within the circulator. Power entering port 1 leaves by port 2 only; power entering port 2 leaves by port 3 only, etc. This one-way power flow between ports results from rotation of the signal polarization between ports. Each port is so oriented that it will be cut off for all signals except those which entered the port just before it. Each port, if it is properly terminated, will accept all of the power from the preceding port. A four-port circulator may be used as a radar duplexer. The load at port four absorbs any local oscillator signal from the receiver and prevents if from being radiated.

CHAPTER 8

PRINCIPLES OF RADAR

The purpose of this chapter is to review the principles which determine the characteristics of radar circuits and to follow this review with a discussion of how these circuits are applied in a typical multipurpose pulse modulated radar set.

RADAR PERFORMANCE FACTORS

Among the principles which should be reviewed before continuing with the present discussion are certain factors which affect radar performance. Such factors are carrier frequency, pulse width and pulse repetition frequency, duty cycle (relation between peak and average power), beam width, and scan rate. The choices of these arbitary constants for a particular system are determined by its tactical use, the accuracy required, the range to be covered, the practical physical size, and the problem of generating and receiving the signal. Basic information concerning these factors may be found in chapter 6 of Basic Electronics, Vol. II, Navpers 10087-C.

PULSE SHAPE

The shape of the pulse determines range accuracy, minimum and maximum range, and resolution or definition of target. The ideal pulse shape would resemble a square wave having vertical leading and trailing edges. However, equipments do not usually produce the ideal waveforms.

For good range resolution (that is, the ability to separate two targets at nearly the same range), a narrow pulse width is required. If a pulse width of 6 microseconds is used, targets one-half mile apart may be resolved. Remember that 6.18 microseconds equals one-half radar mile.) When the two targets are separated by less than one-half mile, the leading edge of the pulse will be striking the farthest target while the trailing edge of the pulse is arriving at the closest target. This will cause both targets to appear as one on the scope. Thus the narrower the pulse, the better is the range resolution.

From the foregoing it would seem that an extremely narrow pulse would be desirable. This is not always the case. In order to be detected, a target must return an echo that is strong enough to cause an indication on the scope. The energy in the returned echo may be increased by increasing the peak transmitted power or by illuminating the target for a longer period of time. Longer target illumination may be achieved by increasing the pulse width. The peak power that a radar transmitter may produce is limited by the size and quality of its power supply, magnetron, waveguides, and other components. Therefore, it is usually, more practical to design a radar with a lower peak power, increasing the pulse width to maintain a sufficient total energy level.

There are also other practical limitations to the minimum pulse width that can be used. Narrow pulses require a receiver with a greater bandwidth. (This is due to the harmonic content of a narrow pulse.) This reduces the gain of the receiver and increases noise.

The ideal pulse with perfectly vertical leading and trailing edges is not attainable. To have perfectly vertical sides (zero rise and fall times) would require an infinite bandwidth. In actual practice, rise and fall times 0.001 microsecond (10 nanoseconds) are commonplace. The steepness of the leading edge is a predominant factor in the accuracy of range determination. Slope of the trailing edge causes the receiver to remain blanked longer than necessary, reducing minimum range performance and target resolution.

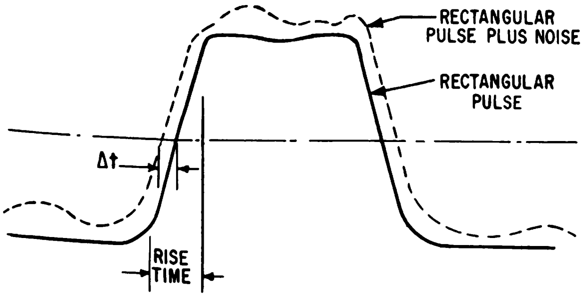
Noise may also affect the shape of the pulse, thereby affecting the accuracy of range measurements. Figure 8-1 illustrates a typical pulse shape with a pulse corrupted by noise superimposed (shown by the dotted line). The time delay from transmitted pulse to received echo will be shortened by the amount Δt.

Notice that if the rise and fall times were zero, noise would affect only the amplitude of the pulse and would not affect range accuracy. For large signal to noise ratios, the slope of the pulse plus noise is the same as the slope of the uncorrupted pulse.

PULSE REPETITION FREQUENCY

The pulse repetition frequency (PRF) largely determines the maximum range and, to some degree, the accuracy of a radar set. The actual time elapsing between the beginning of one pulse and the beginning of the next, called the pulse repetition period, is the reciprocal of the PRF. Thus, for example, if the PRF is 400 Hz, the pulse repetition period is 1/400 seconds, or 2,500 microseconds. When the PRF is too high—that is, when the period between pulses is too short—the echo from the farthest target may return to the receiver after the transmitter has emitted another pulse, making it impossible to tell whether the observed pulse is the echo of the pulse just transmitted or the echo of the preceding pulse. Such a condition is referred to as range ambiguity.

Although the pulse repetition rate must be kept low enough to attain the required maximum range, it must also be kept high enough to avoid some of the pitfalls a single pulse might encounter. If a single pulse were sent out by a transmitter, atmospheric conditions might attenuate it, the target might not reflect it properly, or moving parts—such as a propeller—might throw it out of phase or change its shape. Thus, information derived from a single pulse would be highly unreliable; but by sending many pulses, one after another, many good ones will return. The equipment will integrate or sum up the good points of all the pulses and present you with a clear, reliable picture. Equipment is therefore designed in such a way that many pulses (10 or more) are received from a single object. In this way, effects of fading are somewhat reduced. At short ranges the repetition frequency is increased in order to insure accurate measurements. Many echoes are received from one target, and the integrating effect is increased.



AT. 495

Figure 8-1.—Noise distorted radar pulse.

Tactical employment of a radar set determines, to a large degree, the PRF to be used. Long range search sets require a pulse rate slow enough to allow echoes from targets at the maximum range to return to the receiver before the transmitter is again pulsed. Higher pulse rates are used in aircraft interception sets where the maximum range is less.

The following equation will readily determine either the PRF or the range if one of them is known:

$$\text{PRF} = \frac{\text{Speed of Light}}{2 \times \text{Range}}$$

(Multiplying range by 2 converts range to radar range.) Thus a radar with a PRF of 800 Hz could operate to a maximum range of about 100 miles without range ambiguity. Most radar equipments use 2,000 yards as the standard radar mile; the difference between it and the nautical mile (6,076 feet) is approximately 1 percent.

In theory it is desirable to strike a target with as many pulses of energy as possible during a given scan. Thus, the higher the PRF the better. A high PRF combined with a narrow pulse improves angular resolution and range rate accuracy by sampling the position of the target more often. However, we have shown that tactical employment limits the PRF.

POWER OUTPUT

The ability of the transmitter to provide sufficient power is also a limiting factor. Increasing the PRF increases the average power a proportional amount as shown by the equation

Average Power = Peak Power x Pulse Width x PRF

The useful power of the transmitter is that contained in the pulses and is termed the peak power of the system. Power is normally measured as an average value over a relatively long period of time. Since the radar transmitter is resting for a time which is long with respect to its operating time, the average power delivered during one cycle of operation is extremely low compared to the peak power available during the pulse time. High peak power is desirable to produce a strong echo at the maximum range of the equipment. Low average power enables the transmitter tubes and circuit components to remain cooler while operating and thus can be made smaller and more compact.

SCAN RATE AND BEAM WIDTH

Another factor affecting the PRF is the rate of angular motion of the antenna in searching extensive regions. If the antenna is moved through too large an angle between pulses, not only will the number of pulses per target be too low, but there may even be areas in which targets may exist without their being detected. In this connection, still another factor to consider is the sharpness of the antenna beam. A sharp beam must be pulsed more often than a wide beam to avoid skipping over targets.

The following equation shows the relationship of the antenna beam width, PRF, and antenna scan rate:

$$N_B = \frac{\theta_B f_r}{\theta_s}$$

where

θ_B = antenna beam width in degrees

f_r = PRF in pps

θ_s = antenna scanning rate in deg/sec

N_B = the number of pulses returned from a point target as the antenna scans through its beam width. (Generally, at least 10 pulses must be returned from a point target for reliable detection probability.)

RECEIVER SENSITIVITY

The sensitivity of a radar receiver is its ability to respond to weak echoes; the more sensitive the receiver, the greater the detection range of the radar.

The sensitivity of radar is affected by several factors. Among these are transmitter output, transmitter frequency spectrum, pulse width, losses in the RF line, signal losses in the TR and ATR boxes, and receiver design.

The sensitivity of a radar receiver does not depend on the maximum amount of gain obtainable but on the noise level of the receiver. In other words, the gain could be increased many times above a given figure, but receiver noise would be amplified so greatly that a weak signal could not be seen among the "grass" and "clutter" produced on the indicator scope by the noise. Thus, the noise level of a receiver places a limit on the sensitivity of the receiver. The noise level depends on several factors. The signal-to-noise ratio in the first receiver stage is most important. Increasing the gain increases the noise level as well as the signal level. Receiver gain, therefore, is the result of a compromise between signal amplification and noise amplification.

Though noise voltages are highly undesirable in radar receivers, they cannot be completely avoided due to circuit elements. Although receivers have been built having greater input sensitivity, their operating limit is determined by the noise level within the receiver. When the signal voltage level falls below the noise voltage level, the returning signals are obscured by noise on the indicator. A further increase in amplification is useless because the noise and signal voltages are both amplified equally. Therefore, the highest obtainable signal-to-noise ratio is desired in the input stage of a radar receiver in order that the signal at the indicator is discernible from the noise. The loss of small power in the echo signal or the addition of an equally small noise power in the input stage may reduce the maximum range of the radar set as much as the loss of large amounts of power from the transmitter. Thus, the sensitivity of a radar receiver is measured by the smallest input signal that can produce an output signal discernible against the noise background on the indicator.

In order to obtain as high a signal-to-noise ratio as possible a compromise must be made. If the band-pass of the IF amplifiers is increased, the pulse shape will be maintained as desired but the noise, which is random frequencies, will also be amplified.

If the band-pass of the IF amplifier is decreased, the random frequency noise will be decreased but the pulse shape will be distorted. (This distortion is due to the composition of the square pulse desired which contains many harmonics.)

RF amplifiers are normally not used due to their high noise level when operating in the microwave region. This noise level is due to thermal agitation, shot noise, and induced grid noise. A remedy for noise created in microwave amplifiers is the traveling wave tube, discussed in chapter 7 of this manual. This tube is in fleet use.

The compromise, therefore, is the allowable distortion of the echo pulse versus the acceptable noise level.

BASIC RADAR SYSTEM

Radar sets currently used in aviation vary greatly in detail and in the function they are designed to accomplish. They may be very simple or, if more accurate data is required, they may be highly refined. However, the principles of operation are essentially the same for all sets. Thus, a single basic radar set can be visualized in which the functional requirements hold equally well for all specific sets. The varying details are due to a choice of specific circuits to fulfill these general functional requirements. In general the degree of refinement of radar circuits increases as the operating frequency of the radar increases. (Microwave frequencies lend themselves to a higher degree of precision in determining angular measurement.)

A typical pulse radar set consists essentially of six basic components—synchronizer (timer), transmitter, antenna system, receiver, indicator, and power supply. The relationship of each component is illustrated by block diagram in figure 8-2 (A).

SYNCHRONIZER

The circuits in an airborne radar system that control or synchronize the operation of the various components of the system are known as timing circuits.

The functions which the timing circuits must perform depend to a large extent upon the purpose of the set, the type of modulator used, and the method of data presentation employed. Thus, the functional block diagram shown in figure 8-2 (A) does not apply to any particular set but shows a method of control (timing) which is used in airborne radar sets.

Figure 8-2 (B) shows the control pulses furnished by the timer and their proper time relationships to the transmitted pulse.

The first pulse (waveform (1), fig. 8-2 (B)) is the transmitter trigger. It causes a pulse of RF energy to be transmitted as shown in waveform (2). The transmitter trigger also acts as a reference point from which the other operations are timed.

The timer also supplies a trigger pulse to start the range sweep as shown in waveform (3). However, in some radar sets both the transmitter trigger and the range sweep trigger are delayed. The transmitter trigger delay is a fixed amount, and the range sweep delay may be varied to allow the start of the range sweep as desired. This enables the range sweep trigger to start the sweep at exactly the same time as the transmitter fires, regardless of any inherent delay in the sweep circuit. This time is usually referred to as time zero (t_0), shown as the dotted line in figure 8-2 (B).

Another voltage which the timer may supply is an intensifier pulse, waveform (4), usually referred to as an intensity gate. The intensity gate functions to blank the indicator except during the time of the desired range sweep. Thus, signals arriving outside the time interval corresponding to the desired range are eliminated. The intensity gate shown in waveform (4) is applied to the grid of the CRT. This gate cancels the CRT's disabling voltage, thus allowing the video signal to intensity-modulate the electron stream. An alternate method is to make the CRT normally operative and to apply a negative gate, or blanking pulse, to blank the screen when signals are not to be received.

An important function of any radar set is the determination of range of the targets observed. The methods of range determination vary. Some use a simple transparent overlay (upon which ranges are marked) for the indicator screen. Others have complex circuits used for very accurate range measurements.

One method is the use of rangemarkers generated in the timer. The markers are pulses of very short duration, as shown in waveform (5) of figure 8-2 (B). These pulses, separated by specific intervals of time, are applied to the indicator in the same manner as video signals. They appear as straight lines on a B-type

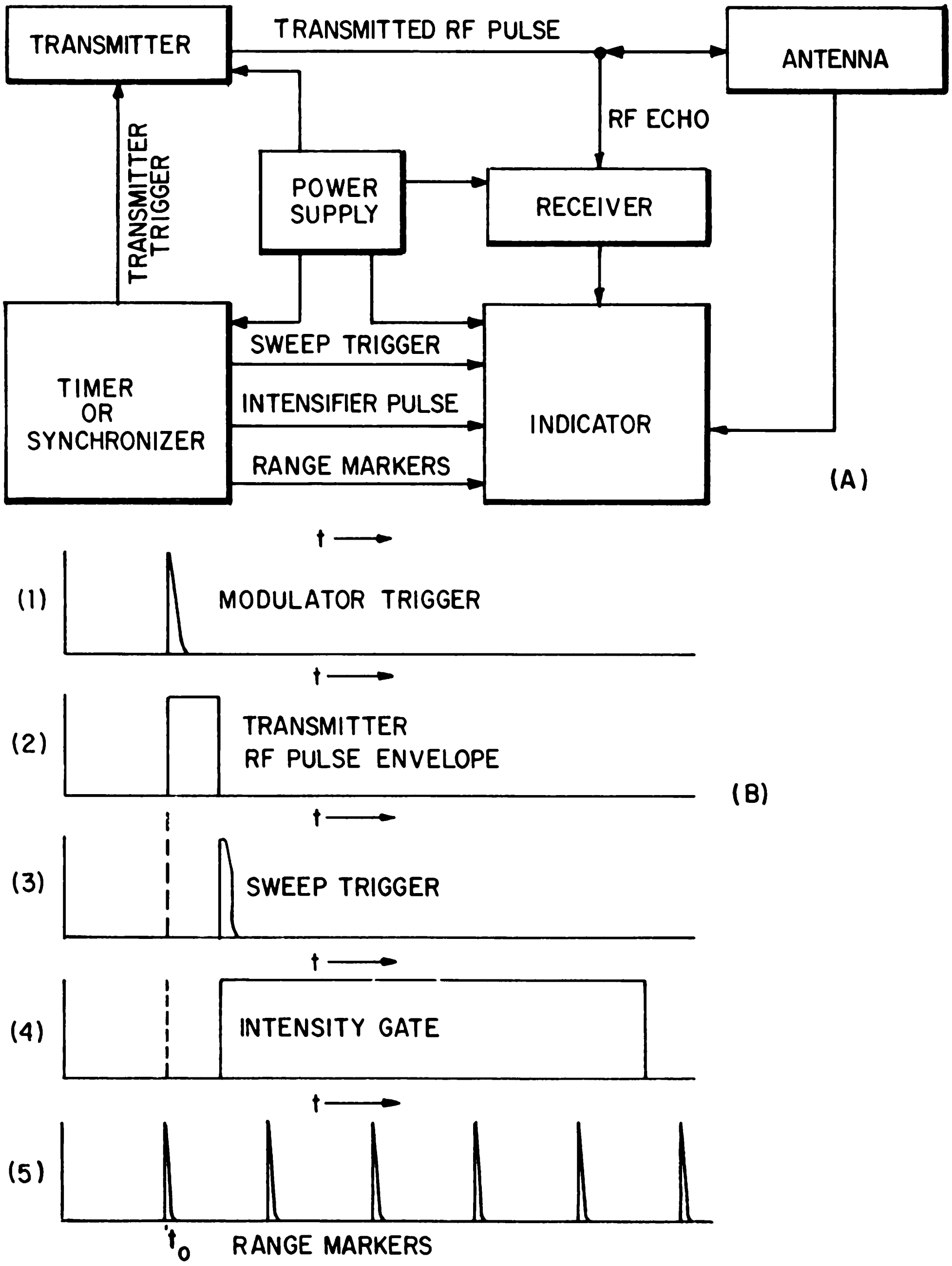


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Figure 8-2.—(A) Block diagram showing functions performed by a typical radar timer; (B) synchrogram of control pulses furnished by the timer shown in figure 8-2 (A)

indicator or circles on a PPI - type indicator. (NOTE: Indicators are discussed in chapter 10 of this manual).

All the control pulses described and illustrated in figure 8-2 (B) are repetitive; that is, they appear once during each cycle of operation. The timer furnished several series of pulses, each having the proper waveform and time relationship to the others. In order that a timer may provide these control pulses, it must contain the following elements:

1. A master oscillator to determine the pulse repetition frequency (PRF). This is usually a multivibrator.
2. A means of forming pulses of the desired shapes and time relations (usually miltivibrators, blocking oscillators, and delay circuits).
3. Circuits capable of matching the waveform generator to either its output circuit or to a transmission line without distortion of the waveform (the cathode follower).

All of the previously mentioned circuits have been discussed in detail in Basic Electronics, NavPers 10087-C.

Multivibrator Timer

The multivibrator type master oscillator is used in most airborne radar systems, and is usually referred to as the heart of the radar. The multivibrator timer may do the following:

1. Establish the pulse recurrence frequency.
2. Trigger the rangemarker generating circuits.
3. Trigger the sweep circuits.
4. Trigger the transmitter.
5. Establish a time base for the intensity gate.

Figure 8-3 is a simplified block diagram of a synchronizer utilizing a multivibrator as the master timer.

The master trigger multivibrator is free running. Its output frequency, which is determined by the time constants of the RC networks in the grid circuits determines the PRF of the set. Figure 8-4 is an illustration of a free-running multivibrator. C1R3 and C2R4 make up the RC networks in the grid circuits.

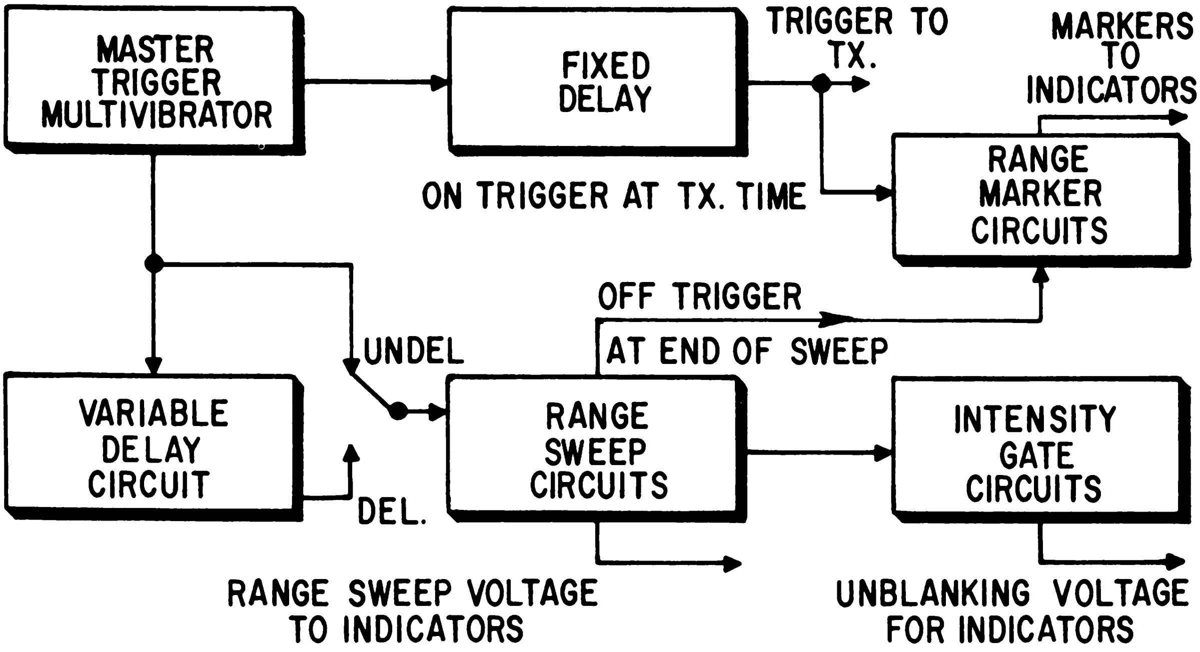

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Figure 8-3.—Simplified block diagram of a synchronizer using a multivibrator master timer.

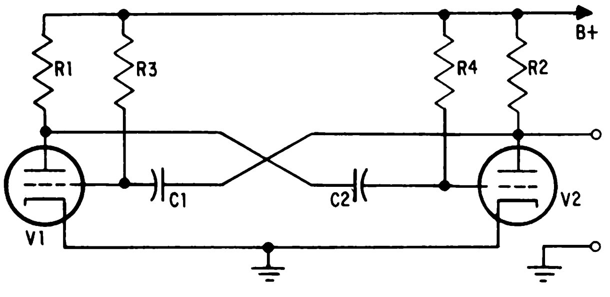

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Figure 8-4.—Free-running multivibrator.

The output taken from the plate circuit is fed to the fixed delay circuit for firing the transmitter and the variable delay, or directly to the range sweep circuits if no sweep delay is to be employed. (Refer to fig. 8-3). The fixed delay circuit delays the firing of the transmitter until the nonlinear portion of the range sweep is past. The output of the fixed delay is then fed to the modulator and range marker circuits simultaneously. Thus, the range-marker circuits are turned on at the time the transmitter fires, and turned off at the end of the range sweep time by a pulse from the range sweep circuits. The output of the range marker circuits is fed to the indicator in the form of evenly spaced pulses and appear as intensified range lines on the scope.

The trigger to the range sweep circuits may be either delayed or direct. If direct, the range sweep will start immediately; if delayed, the range sweep will start sometime after the transmitter is fired, delay time being equal to the output of the variable delay circuit.

The range sweep circuits provide the indicator with sweeps of various time duration (ranges). They also furnish trigger pulses to start and stop operation of the intensity gate circuit (for unblanking the indicator during sweep time only), and an output to the rangemarker circuits to turn the marker circuits off at the end of sweep time.

TRANSMITTER

The transmitter is a high powered, high frequency microwave oscillator. It is designed to operate around a predetermined frequency and to be fairly stable at this frequency. It operates during the pulse period and is then shut off for a comparatively long rest period. Its power, in the form of high frequency microwave oscillations, is delivered during the pulse time to the waveguide transmission system for delivery to the antenna, where it is then propagated into space.

The block diagram (fig. 8-5) is a simplified drawing and does not refer to any particular type of transmitter; however, it contains the elements found in a majority of airborne radar systems.

The technician should bear in mind that the various components discussed may be physically located in one unit or in several different units, depending on the type of installation.

Functional Operation

Referring to figure 8-5, the trigger shaper receives an input trigger from the system's synchronizer. As the name implies, the trigger is amplified and shaped into a sharp trigger pulse and fed to the next stage, a cathode follower. The cathode follower is used to match the high output impedance of the trigger shaper to the low input impedance of the pulse switch stage. The output from the cathode follower is applied to the control grid of the pulse switch. Before discussing the triggering action,

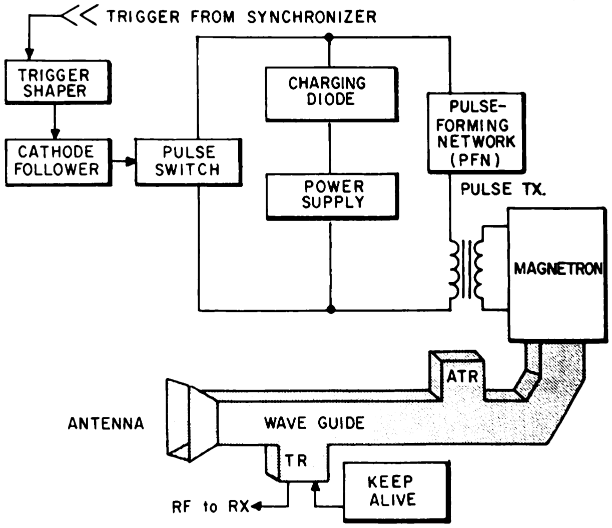

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Figure 8-5.—Radar transmitter (block diagram).

the function of the power supply, charging diode, and pulse forming network are discussed.

The power supply furnishes the high voltage and supplies the energy which the pulse forming network (PFN) stores for release to the transmitter. The PFN, an open end artificial transmission line, stores this energy, and determines the width and shape of the pulse to the transmitter. The charging diode controls the transfer of energy from the power supply to the PFN. The use of an inductive charging impedance causes the PFN to charge to approximately twice the power supply voltage. It also prevents the power supply output from being shorted during the pulse time when the switch tube conducts.

The pulse switch, when triggered, acts like a closed switch which completes the circuit for discharge of the PFN very rapidly through the primary of the pulse transformer. The pulse transformer matches the impedance of the transmitter to the characteristic impedance of the PFN, and thus results in maximum power transfer. Also by using a step-up transformer (from the PFN to the transmitter), a lower voltage may be used on the PFN for a given pulse voltage to the transmitter.

A magnetron is used as the transmitting tube in most pulsed transmitters operation at frequencies above 1000 MHz. The fact that the magnetron has the capability of high power outputs and is not subject to the change in input impedance at high frequencies encountered in conventional tubes, makes it well suited for use at these high frequencies. Several types of oscillators have been developed which compete with magnetrons as radar high-powered oscillators, such as the velocity modulated types, the back-wave oscillator, and the klystron, which operate in the radar range and are capable of greater power output than the triodes.

The magnetron, which is a self-excited oscillator, possesses fair frequency stability as compared with the more stable lower frequency oscillators (electron coupled or crystal controlled). However, the overall system will provide adequate stability when automatic frequency control (AFC) is used with the local oscillator.

As explained in Basic Electronics, NavPers 10087-C, the magnetron is a type of diode using an axial magnetic field which is perpendicular to the electric field that exists between the cathode and the anode. This magnetic field is usually provided by a permanent magnet.

The tube consists of a cylindrical plate, with a cathode positioned coaxially inside it. The tuned circuits in which the oscillations take place are resonant cavities in the plate.

The duplexer, which consists of an ATR and a TR, is used to enable the use of one antenna for both the transmit and receive cycle of the system. The TR device effectively blocks the transmitter's energy from entering the receiver during transmit time—the ATR device insures that all reflected energy is directed to the receiver during receive time. The actual construction and operation of the TR and ATR devices are discussed later in this chapter.

Prior to the actual circuit analysis of a typical airborne radar transmitter, it is necessary that you first have an understanding of the various components used in conjunction with the transmitter, their uses, construction, and theory of operation.

ANTENNA SYSTEM

The antenna system has two general purposes. It radiates pulses of microwave energy developed by the magnetron, confining the waves into a narrow beam. In addition it receives the echo signals from targets which are applied to the receiver. The antenna system consists of waveguides, switching tubes, a reflector for beaming the radiated energy and concentrating the received energy, a mechanism for rotating the reflector during operation, and servo units which coordinate the position of the indicator sweep with the position of the antenna reflector.

Duplexers

In present day aviation radar, it is desirable to use a single antenna for both transmitting and receiving. A fast acting electronic switching device is required to disconnect the receiver from the transmission line during periods of transmission and to disconnect the magnetron during periods of reception. The receiver must be disconnected in order to protect the receiver input section and crystal since the magnetron output may be several megawatts. The magnetron must be disconnected during periods of reception in order to allow all available reflected energy from the target to pass to the receiver.

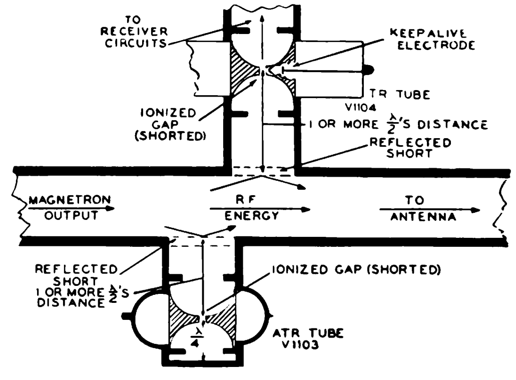
The duplexer is the device which performs this dual function of switching the antenna for transmitting and receiving, and protecting the receiver against the high power pulse from the transmitter. In addition, there is one device which is sometimes used in conjunction with the duplexer which should be mentioned at this time, although it is not a true duplexer.

A CRYSTAL SHUTTER is frequently used as a protective device for the receiver crystal while the radar is turned off, due to the possibility that energy radiated from nearby radars may damage the crystal. A typical shutter assembly may consist of a waveguide gate and a solenoid that controls the position of the gate. When the radar system is not in operation the solenoid is not energized and the position of the gate is such that it causes a virtual short circuit across the waveguide path to the receiver input. When the radar system is in operation, the solenoid is energized and causes the gate to move from the waveguide to a position where it will offer no interference to signals traveling to the receiver.

TR AND ATR TUBES.—A simplified cross section view of a waveguide system duplexer is shown in figure 8-6. These tubes are a spark gap enclosed in a gas filled envelope. They are practical for this function because of the tremendous power difference between the transmitted and received signal. Ionization occurs during the transmitter pulse period and causes the tube to function as a short circuit or closed switch. During the reception period these tubes remain de-ionized because the received signals are low power; thus they appear as an open circuit.

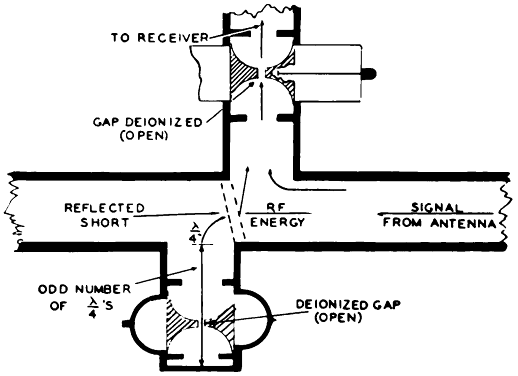
The TR tube is used to protect the crystal mixer and the receiver circuits during transmission. When the magnetron fires, sufficient voltage is impressed on the TR tube to ionize it completely and break down the gap, producing an effective short circuit. Since the TR tube is placed an even number of quarter wavelengths from the waveguide a short circuit existing within the tube reflects an effective short circuit at the entrance of the receiver T-junction. This prevents the RF pulse from reaching the crystal and the receiver, but permits it to flow freely to the antenna.

The operation of the duplexer during transmission is shown in (A). After the pulse has passed, the tube de-ionizes and again presents a high impedance at the entrance of the receiver T-junction. This allows any reflected signals to reach the crystal mixer. Duplexer action during signal reception is shown in (B).



TRANSMISSION OF PULSE

(A)



SIGNAL RECEPTION

(B)

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Figure 8-6.—TR/ATR action in a waveguide.

The ATR tube is located an even number of quarter wavelengths from the waveguide; thus when the transmitter fires, which breaks down the gap of the ATR tube, an effective short circuit is reflected across the opening at this T-junction. This causes the wall to appear continuous to the transmitter energy; thus the energy passes unimpeded.

The ATR waveguide section is so constructed than an even number of quarter wavelengths exists between its gap and the opening to the waveguide. During signal reception, the ATR tube is de-ionized and causes an effected open circuit to appear at the opening of the ATR junction. This causes a reflected short across the waveguide adjacent to the TR opening, as illustrated in (B). The received signal is guided into the TR cavity instead of continuing to the magnetron.

Notice that both tubes in this illustration are in the narrow section of the waveguide; thus they are E-type junctions, but they could just as easily have been in the wide dimension, making them H-type junctions.

Characteristics of TR and ATR Tubes.—At sea level pressure approximately 30,000 volts are required to break down a spark gap of 1 inch. Approximately 50 volts is required to maintain ionization; this is known as running voltage. Once the voltage has been removed, a lapse of approximately 10 μsec is required for de-ionization. By enclosing the spark gap in a partially evacuated envelope, the breakdown voltage will be reduced as well as the running voltage and the de-ionization time.

For efficient transmitter operation it is important that the power dissipated by the TR tubes is small as compared to transmitter power. Also the TR tubes must maintain a properly matched line while they are fired. During the time that the transmitter is fired the TR tubes must afford sufficient attenuation to prevent the power that leaks into the receiver from being of so great an amplitude that it may damage the receiver crystal. To allow scope presentation of nearby targets it is necessary that the TR tubes de-ionize rapidly.

The amplitude and duration of the ignition spike must be reduced to the extent that the receiver crystal will not be damaged. This is accomplished by providing a keep-alive voltage to the TR tubes. TR tubes that perform this function contain three electrodes, two of which provide the main gap which does the switching; the third is called the keep alive electrode. This keep-alive electrode is mounted close to one of the other electrodes. It is connected to a relatively high direct negative potential which causes steady partial ionization of the gas between it and the main electrode. This insures almost instantaneous firing of the TR tube for each pulse of the magnetron.

Recovery time may be described as the time required for a TR tube to de-ionize effectively. The length of the recovery time period is determined by the length of time required for the free electrons and ions, that remain in the gas after the transmitter pulse has been removed, to recombine. A short recovery time means that target echoes can be received sooner after the transmitter pulse ends.

The life of a TR tube is relatively short as compared with most other tubes. A major factor that shortens the life of these tubes is the gradual loss of gas pressure. This is the result of chemical combination of the gas and the tube electrodes; also molecules of gas become embedded in the electrodes as a result of glow and keep-alive discharge.

One means of lengthening the life of these tubes is to maintain the keep-alive current within design limits. Some equipments provide test points for making current checks. A reading lower than the normal minimum current will most likely be an indication that the TR tube is not operating at proper efficiency.

The most general indications of defective TR tubes are as follows:

1. Receiver recovery time will increase.
2. Receiver sensitivity will decrease.
3. Receiver crystals will become defective. (This will be indicated by an increase in crystal back current.)

Some radars use the same type tube for TR and ATR operation. In some cases a tube that will not operate as a TR may be used satisfactorily as an ATR; thus for emergency operation the tubes may be interchanged.

HYBRID DUPLEXER.—A type of duplexer somewhat different from those already discussed is the HYBRID RING. This duplexer is capable of performing the duties of the conventional ones already discussed, and in addition it has a low standing wave ratio and the ability to transfer high power.

The hybrid ring is a form of hybrid junction, which is a device that transmits power to two lines from each of two independent inputs that are not coupled together. This type of junction is frequently referred to as a "magic-T."

NOTE: This statement holds true for the hybrid ring duplexer only during reception; thus the magnetron is not coupled to the antenna and there is no dissipation of received power by the magnetron. The magic-T is discussed in greater detail later in this chapter.

During the transmitter pulse the duplexer does not function as a true hybrid ring because the ionization of the TR tubes by the high power transmitter pulse serves to couple the magnetron to the antenna. The TR tubes also perform their normal protective action for the receiver crystal.

RADAR RECEIVERS

Earlier in this chapter the importance of developing an extremely high powered pulse by the transmitter was discussed. Although the high power pulses are radiated in a narrow beam, only a small part of the radiated energy actually strikes a distant target. Since the energy striking the target is reflected or radiated over a wide angle, only a very small part of the transmitted energy is returned to the radar's antenna. Thus, the function of the radar receiver is to receive the weak target echoes from the antenna and amplify them sufficiently to provide the indicator with the desired target information. Consequently, the weaker the signal which the receiver can use, the greater the effective range of the radar set.

Before considering the detailed operation of the radar receiver, some of the requirements it must fulfill will be discussed. However, the discussion will be limited to those requirements that are within the scope of this manual.

With the exception of some superregenerative IFF receivers, all modern radar receivers are of the superheterodyne type. The compnents of a typical receiver are a mixer, local oscillator, IF amplifiers, video detector, video amplifiers, and output provisions for built-in or remote indicators. The use of conventional RF amplifiers becomes progressively less practical from the lower radar frequencies to the higher and therefore are not used extensively in the microwave region. In cases where RF amplification can be used, the RF amplifier is placed ahead of the mixer. (Such application utilize traveling wave tubes.)

Improved receiver design has probably done more to improve the usefulness of radar than any other one thing. Radar receivers are quite sensitive, having been perfected to the point where they will accept signals in the order of a pico watt and will amplify and display them in many useful ways. The weaker the signal which a receiver can accept and efficiently display, the greater is the effective range of the set.

Signal-To-Noise Ratio

The name commonly given to small random fluctuating voltages present in the input stages of radar receivers is noise. In a radar set the noise voltages cause unwanted deflections of the electron beam in electrostatic deflection systems, and erratic fluctuations in intensity of the beam in intensity modulated systems.

Signal-to-noise ratio as well as proper bandwidth are important properties which are designed and built into receivers.

The noise level, at microwave frequencies, is practically all within the receiver. Most of the noise is generated in the amplifier stage and includes thermal agitation, shot effect, and induced voltages. Good design reduces these unwanted noises to a minimum but a strict maintenance schedule is necessary to maintain peak performance.

Bandpass

The input to the receiver amplifiers consists of minute rectangular pulses of RF energy. It should be recalled from Basic Electronics that a perfectly square wave consists of a fundamental frequency sine wave plus an infinite number of odd harmonics. Thus, to pass signals of this broad frequency range, radar receivers use amplifiers that have a relatively wide bandpass characteristic. Improper alinement of the receiver's amplifiers may cause distortion and loss of gain, resulting in poor target definition, reduction of range, and reduced accuracy of range measurements.

Radar receiver bandwidths may vary from 1 to 10 megacycles. The noises contained within the receiver include frequency components throughout the entire frequency spectrum and are, therefore, affected by the bandwidth of the receiver. Generally, a reduction in bandwidth reduces the noise voltage but does so at the expense of pulse shape. The amount of permissible distortion of the pulse shape thus limits the reduction in noise which may be accomplished by reducing the receiver bandwidth.

Tuning

Radar transmitters (magnetrons) used in aviation equipment have relatively poor frequency stability. As the radar antenna rotates, the antenna impedance may change. Thus, the load presented to the transmitter changes, and the output frequency of the magnetron changes. Other inherent factors cause considerable magnetron frequency shift over longer times. When the output frequency of the magnetron changes, the receiver must be retuned automatically if it is to receive the reflected echoes. Therefore, radar receivers must have the necessary circuitry to provide for automatic tuning—commonly called automatic frequency control (AFC).

Functional Operation

Radar receivers found in aviation equipment use superheterodyne circuits of the single-conversion type (single-intermediate frequency). Superheterodyne receivers are discussed in detail in Basic Electronics, Vol. 1, and should be studied prior to continuing in this chapter. Although the receiver circuits discussed are primarily broadcast and communication receivers, their basic principles of operation are applicable to radar receivers.

Radar receivers differ from communication receivers in the following respects: (1) most radar receivers must detect received signals of approximately the same amplitude as the random noise generated by resistors, vacuum tubes, and other electronic components in its input stage; (2) radar receivers must be much more sensitive than communication receivers, in which static limits the smallest signal that can be heard; and (3) radar receivers must receive very short pulses of RF power reflected from distant targets. The pulses returned to a radar receiver have widely varying amplitudes and distorted waveshapes. To determine target range accurately, pulse wave fronts must rise very rapidly. To reproduce these rapidly changing signals, the radar receiver band-pass must be very wide.

The block diagram illustrated in figure 8-7 is representative of a typical superheterodyne type radar receiver which is found in most airborne radar sets.

Referring to the block diagram, it should be noted that RF energy from the antenna is fed to the mixer. Crystal mixers are used as the first stage in radar receivers because of their high signal-to-noise ratio.

The local oscillator, a special type high-frequency oscillator called a klystron, couples its output through the waveguide to the mixer. The theory of operation, its adjustments, and

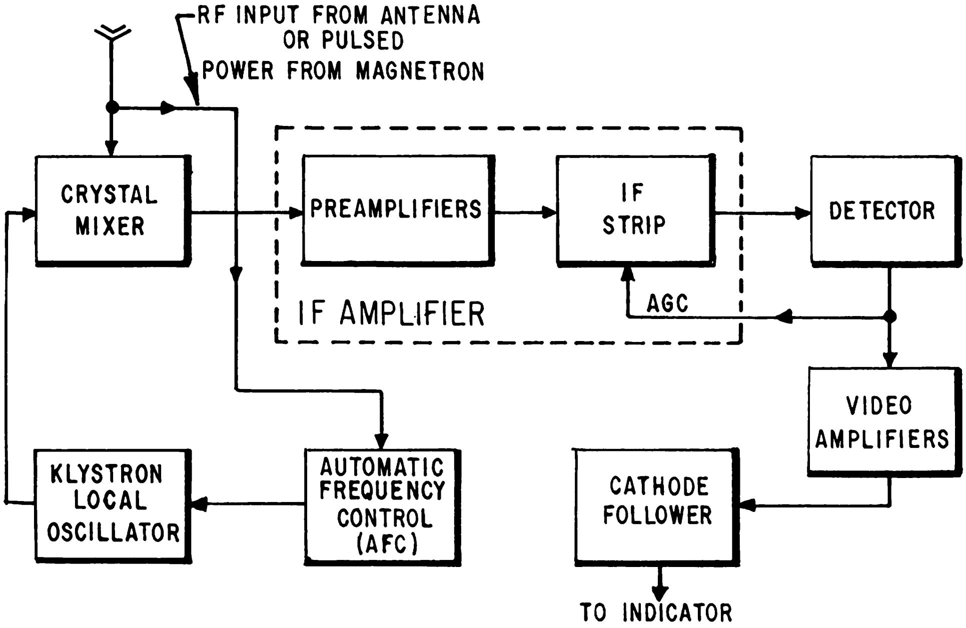
RF INPUT FROM ANTENNA OR PULSED POWER FROM MAGNETRON
CRYSTAL MIXER
PREAMPLIFIERS
IF STRIP
DETECTOR
IF AMPLIFIER
AGC
VIDEO AMPLIFIERS
KLYSTRON LOCAL OSCILLATOR
AUTOMATIC FREQUENCY CONTROL (AFC)
CATHODE FOLLOWER
TO INDICATOR

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Figure 8-7.—Block diagram of a radar receiver.

tuning procedure will also be discussed later in this chapter. The local-oscillator frequency beats with the transmitter frequency (heterodyne action) and produces the IF (intermediate frequency), which is the frequency resulting as the difference between the local-oscillator and the transmitter frequencies. This difference frequency may range from 30 to 100 MHz, but in most receivers the IF is either 30 or 60 MHz.

The IF amplifier consists of a preamplifier and an IF strip. The preamplifier is physically located near the crystal detector to prevent loss or attenuation of the signal before it can be amplified. The input circuit of the first preamplifier stage is tuned to the intermediate frequency, which is the difference between the transmitter and local oscillator frequencies, and bypasses all other unwanted frequencies to ground. (NOTE: It is in this section of the receiver where noise generation must be rigidly controlled.) The preamplifier normally consists of at least two stages of amplification, the first of which may be a cascade type. Its output is fed to the main amplifier which is normally referred to as the IF strip.

The IF strip consists of several stages of double-tuned IF amplifiers. They are double tuned to broaden the band pass of the receiver for better fidelity. The gain of the IF amplifier is normally between 10^6 and 10^{12}, and can be varied by altering either the control grid bias or the screen voltage of one or more stages.

The greatly amplified signal is then fed to the detector, usually a conventional diode detector, where the video signal is removed from the IF carrier. The detector filters used in most airborne radar receivers must be a long RC filter to the IF frequency and a short RC to the video envelope. Thus, the intermediate frequency is shorted to ground and the detected video pulses are passed to the next stage.

The video amplifier receives the detected pulses and amplifies them to the magnitude required to operate the indicator. The input to the video amplifier is in the form of rectangular pulses which are made up of infinite number of odd harmonics. Therefore, the video amplifiers must be designed for a wide band-pass in order to amplify the principal harmonics and preserve the shape of the input waveform.

The output from the video amplifier is fed to the video output cathode follower. The cathode follower is used as an impedance matching device between the video amplifiers and the indicator. It also serves as a power amplifier to drive the indicator. In the case of remotely located indicators, it is also used to match the impedance between the video amplifiers and the interconnecting coaxial cable.

The last block to be discussed in figure 8-7 is the AFC circuit. The AFC circuit is used to automatically adjust the local-oscillator frequency so that the radar receiver is always tuned to the radar transmitter frequency. Remember, the loading of a radar transmitter often changes as the transmitting antenna rotates (scans). The frequency of a microwave oscillator is very sensitive to changes in load impedance. Thus, as the transmitting antenna of a microwave radar is rotated, the transmitter frequency changes. If the local oscillator frequency does not also shift, these frequency changes may be so great that the received signal is outside of the receiver band-pass. In these cases AFC is used to automatically track the radar receiver tuning with the transmitter frequency.

Although many different types of automatic frequency control circuits are used in microwave radars, all AFC systems are basically similar in operation. Practically every AFC system has circuits that produce an output voltage proportional to the change in transmitter frequency. This output voltage changes the local-oscillator output frequency in such a way that the radar receiver remains tuned to the transmitter frequency.

INDICATORS

The purpose of the indicator and its associated components is to display target information supplied by the receiver and antenna system. The indicator may be a relatively simple device such as an indicating light that goes ON and OFF when specific conditions exist, a small meter, or an elaborate assembly containing a cathode-ray tube (CRT). However, in any case the complexity of the indicating system will vary with the amount of information to be displayed to the operator.

In most cases the technician will be working with the CRT type of indicator. This type indicator is the only one discussed in this chapter. CRT indicators may also vary in degree of complexity and may be used to display numerous data simultaneously to the operator. Some of the data presented to the operator are as follows:

1. Target range- as computed between sweep start time and target return time.
2. Range rate, opening or closing—relative speed between viewing radar and target.
3. Target position—range and azimuth; relative to a reference, such as the viewing radar.
4. Artificial horizon—generated by a gyro in the magnetic compass.
5. Steering reference—flightpath to a predetermined position.
6. Altitude, absolute—relative to the viewing radar.

This list, however, should not be construed as being all inclusive.

The indicator or presentation system accepts the radar data such as video pulses, range-marker voltages, sawtooth timing waves, and presents them in a visual display on the cathode-ray tubes. An indicator assembly contains the cathode-ray tube and various electronic circuits necessary for presenting the desired information on the CRT. These circuits include video amplifiers, clampers, and the controls for adjusting the brilliance and focus of the visual pattern.

Two general types of presentation are used in radar indicators-deflection-modulated and intensity-modulated displays. In the deflection method, the video pulse causes a momentary deflection of the cathode-ray electron beam and produces a pip in the trace to indicate a target echo. In the intensity method, the video signal is applied to the element of the CRT which controls the intensity of the electron beam, and the resulting target image is a bright spot of light. Three types of intensity presentations are shown in figure 8-8. A detailed discussion of indicators is made in chapter 10 of this training manual.

MONOPULSE

Monopulse is a simultaneous scanning system capable of obtaining the range, bearing, and elevation of a target from a single pulse. Hence, the name mono (one) pulse. In the monopulse system, the radar radiates into space a single beam whose axis coincide with the antenna axis. Normally, with a single beam fixed with respect to the antenna, a target could move a substantial distance from the antenna's axis before the radar's tracking system would detect a displacement and react. To track a moving target, an error signal is necessary. Error signals are obtained by comparison. In sequential scanning the error signal is obtained by comparing the strength of echo returns from successive pulses. In monopulse systems the pulse is divided into four separate parts in the waveguide system. The four parts are radiated by separate feed horns, and are combined by the antenna into a single beam. Return echoes are divided back into four parts. The relative strength of the parts are compared to obtain target position with respect to the antenna axis (fig. 8-9.)

The heart of this monopulse system is called the microwave comparator. It consists of four feed horns, four hybrid rings, and connecting waveguide sections.

NOTE: Prior to the discussion of monopulse comparator operation, a review of the basic operation of a hybrid ring is considered necessary. This discussion follows.

HYBRID RING REVIEW

The hybrid ring is used principally as a duplexer in a high power radar system. However, a combination of three hybrid rings may be used as a balance mixer. This type of mixer is very effective in isolating the receiver from the transmitter during the time the transmitter is firing.

A simplified version of the hybrid ring used as a duplexer is illustrated in figure 8-10 (A) and (B). The operation during transmission and reception is illustrated in parts (C) and (D), respectively.

During TRANSMISSION (fig. 8-10 (C)), the operation of the hybrid ring may be explained as follows:

1. The field from the transmitter enters arm 3. At the junction with the ring, the field divides into two out-of-phase fields, one moving clockwise around the ring and the other, counterclockwise. (See fig. 8-11 (B) (1)). In order that energy may be coupled to the antenna via arm 1, the E fields arriving at the arm 1 junction must be 180° out of phase (fig. 8-11 (B) (3)).

2. The field moving clockwise around the ring from arm 3 fires the TR tube in arm 4, and the energy is blocked from the receiver or load. A high impedance (equivalent to an open circuit) appears at the junction of arm 4 and the ring. There is a phase reversal at this junction (fig. 8-11 (B) (4)).

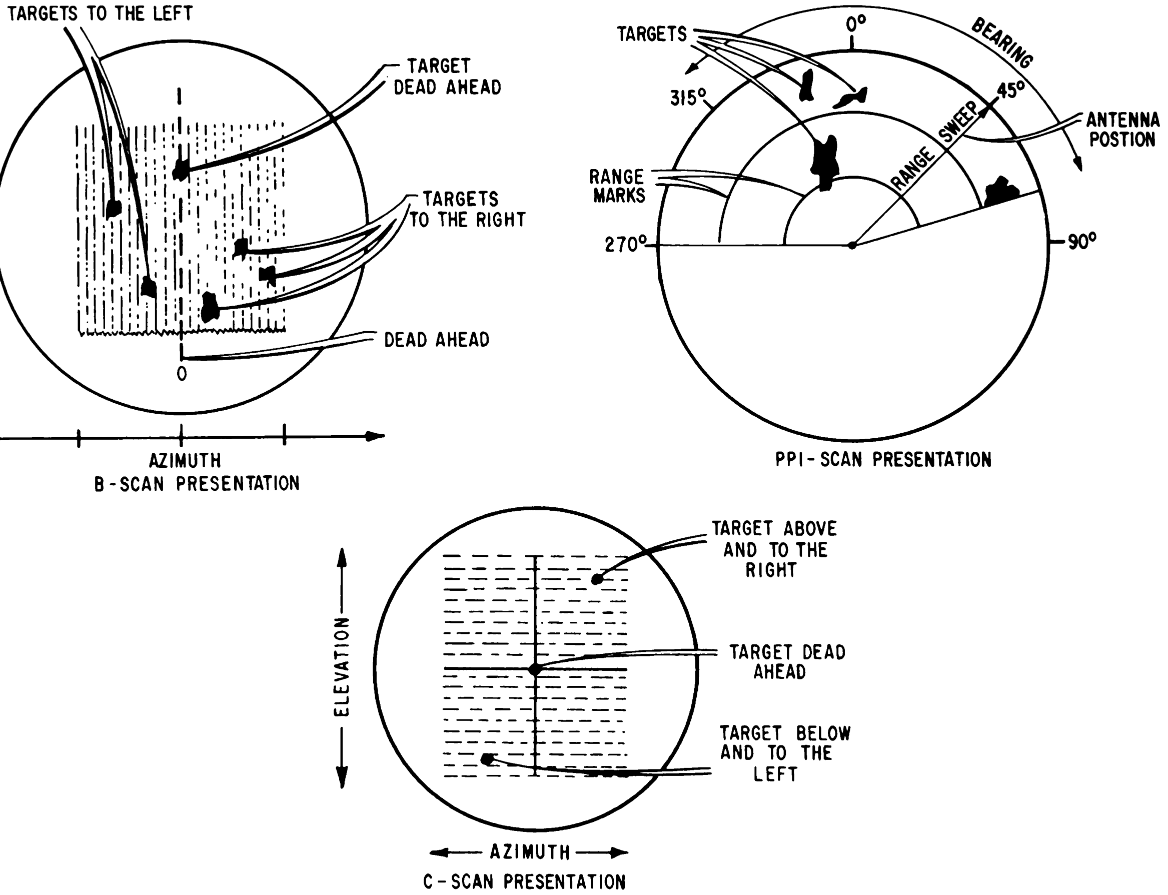

Figure 8-8.—Scan presentation.

he field moving counterclockwise from "sees" a short circuit at the arm 2 when the TR tube in arm 2 fires, and no phase reversal at this junction. ount of energy entering waveguide 2 is by the action of the spark gap (not the figure).

the complete circuits are traced out 0 (C)), it will be seen that the clock- d counterclockwise signals arriving nction of arm 1 are of opposite polarity be propagated through the arm to the (fig. 8-11 (B) (3)).

g RECEPTION (fig. 8-10 (D)), the n of the hybrid ring may be explained s:

1. The relatively weak signal from the antenna enters arm 1 and divides at the junction into two out-of-phase components (fig. 8-11 (B) (1)). To avoid coupling energy into the transmitter via arm 3, in phase signals must arrive from both directions at this junction (fig. 8-11 (B) (2)).

2. The energy moving clockwise around ring from arm 1 is not sufficient to fire the TR tube in arm 2, and energy passes to the receiver through arm 2. There is a phase reversal (arm 2 presents high Z at the junction with the ring (fig. 8-11 (B) (4)), and the remainder of the energy moves clockwise around the ring to arm 3.

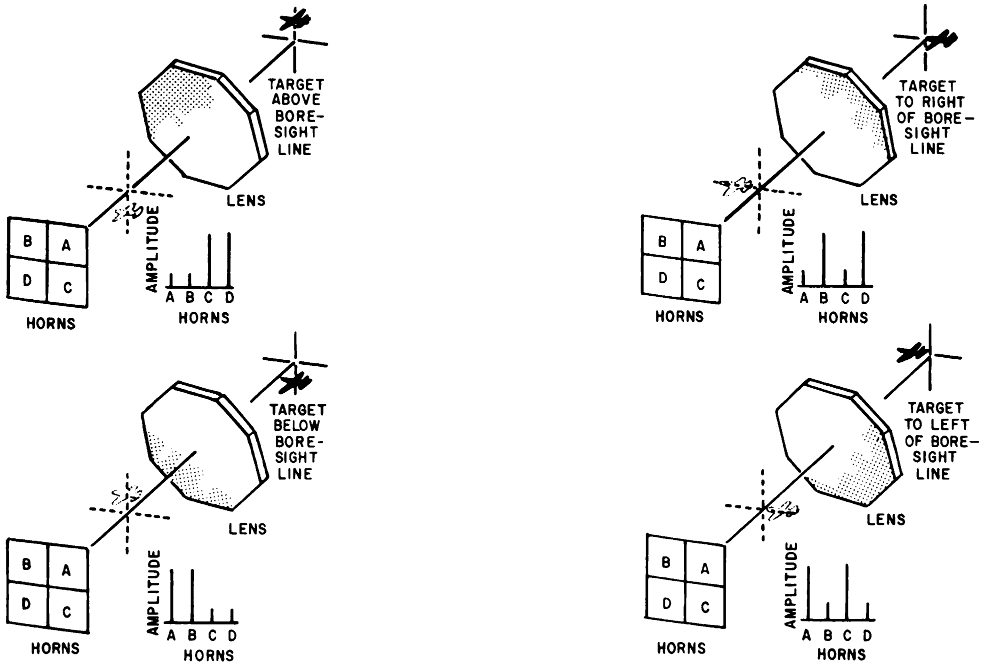

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Figure 8-9.—Amplitude changes of received energy with target position.

3. The energy moving counterclockwise around the ring from arm 1 is likewise not sufficient to fire the TR tube in arm 4, and energy passes to the receiver through arm 4. There is a phase reversal (fig. 8-11 (B) (4)), and the remainder of the energy moves counterclockwise around the ring to arm 3.

4. At arm 3 the clockwise and counterclockwise components are in phase, and no energy is coupled to the transmitter through arm 3 (fig. 8-11 (B) (2)).

Rules for Hybrid Ring Junctions

Hybrid ring junctions are often given a more colorful name: ratrace. These rings are used to add, subtract, and split up RF energy. They also provide switching of energy into appropriate channels. The hybrid ring junctions consist of a waveguide ring with four arms projecting from it. Each arm can be connected to a waveguide section. In the figures of hybrid ring junctions, the symbols delta (Δ) and sigma (Σ) placed by an arm stand for the difference and the sum respectively, of signal amplitudes of single input signals.

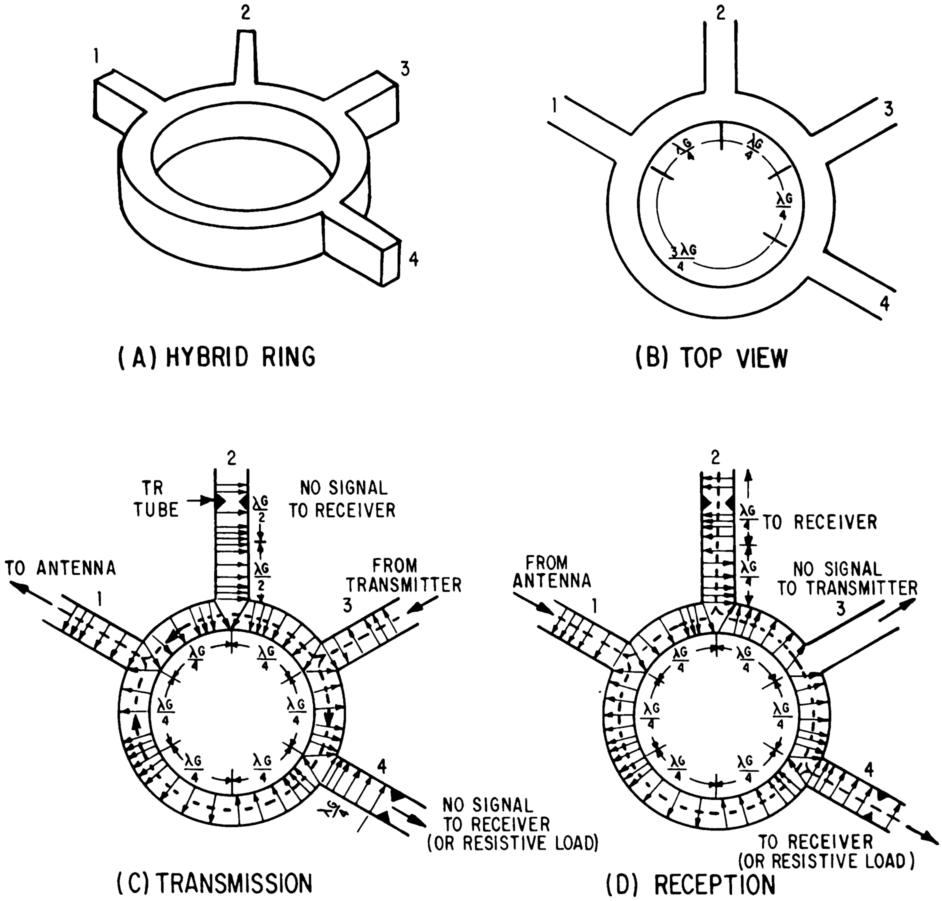
The principle of operation of a hybrid ring can be summarized very briefly by the following rules, which are illustrated in figure 8-12.

1. A signal applied to a Σ (sum) arm will split and leave the ring at two adjacent arms. The output signals will be equal in amplitude, but 180° out of phase with one another.

2. A signal applied to a Δ (difference) arm will split and leave the ring at two adjacent arms. The two output signals from these arms are equal in amplitude and in phase.

3. If in-phase signals are applied to two opposite arms, the output of the adjacent Δ arm will be proportional to the sum of the input signals. The output of the Σ arm will be proportional to the difference of the input signals.

4. If 180° out-of-phase signals are applied to two opposite arms, the output of the adjacent Δ arm will be proportional to the difference of the input signals. The output of the Σ arm will be proportional to the sum of the amplitudes of the input signals.



(A) HYBRID RING (B) TOP VIEW

(C) TRANSMISSION (D) RECEPTION

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Figure 8-10.—Hybrid ring duplexer showing E lines during transmission and reception.

MONOPULSE COMPARATOR OPERATION

A simplified schematic of the comparator is shown in figure 8-13. To find out how it works, first trace out the energy paths during transmission. Transmitter energy enters the summation arm of HY-1. According to the rule 1, the signal splits and leaves the ring at the two adjacent arms. These two signals have the same amplitude, but are 180° out of phase. Then the signals are fed to the summation arms of hybrid rings HY-2 and HY-3. The waveguide lengths between HY-1 and HY-2, and HY-1 and HY-3 are equal; hence the signals enter the rings simultaneously. Again keeping in mind rule 1, the signals in HY-2 and HY-3 divide their energy equally and out of phase with each other. The energy, now divided into four separate signals, is sent to the horn cluster. By varying the waveguide sections between the hybrid rings and horns, the separate signals will arrive at each horn in phase with one another. The energy radiated from the horns combines to form a single wave front. The radiated energy is focused into a narrow circular beam by the lens antenna. Energy does not pass through the difference arms of HY-1, HY-2, and HY-3 because the signals are canceled at these junctions by proper waveguide matching. If energy were allowed to pass through these arms, it would burn out the mixer crystals, and possibly the receiver.

Echo returns are focused by the lens into the four horns. The amount of energy entering each horn is determined by the position of the

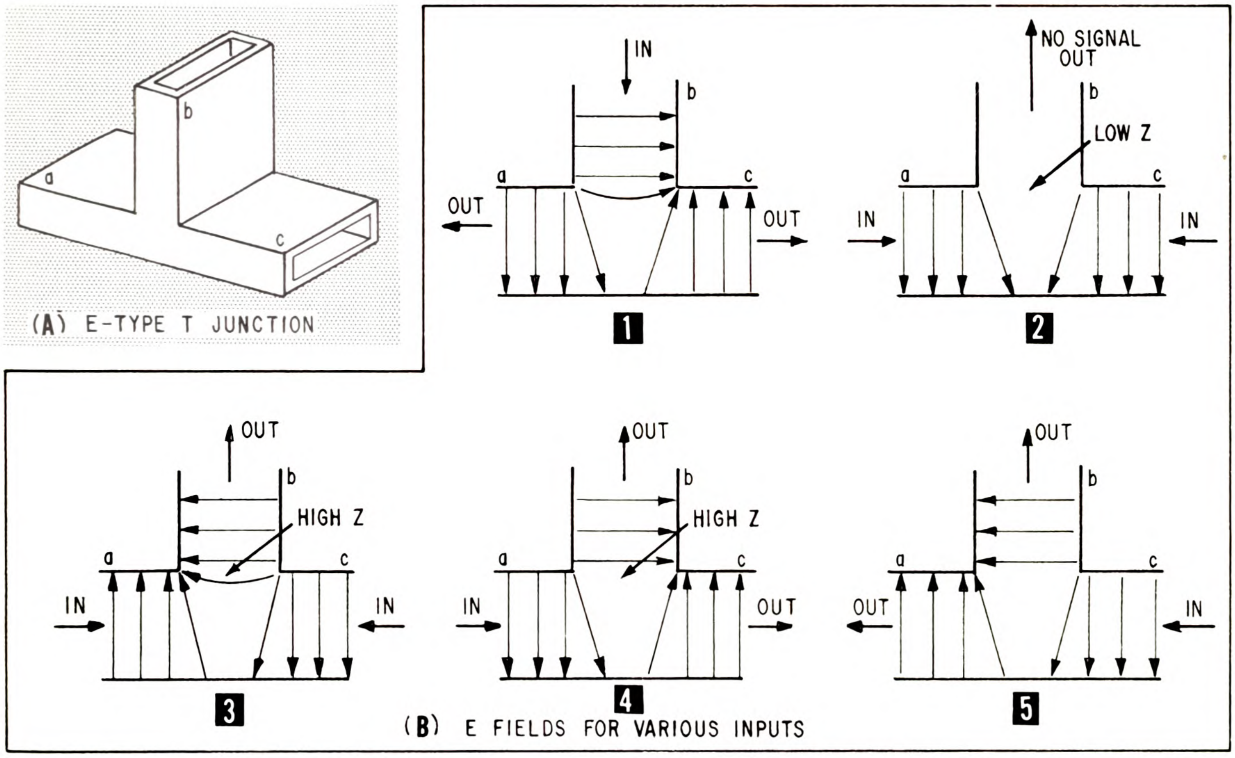

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Figure 8-11.—E-type T-junction and E field.

target with respect to the antenna axis. Phase inversion of the energy takes place due to the lens. Returned energy is combined in the four hybrid rings of the comparator. The comparator compares the amplitude of the energy in each horn, and produces a sum signal and two difference signals. The sum signal is used for ranging and also provides a reference for the elevation and traverse tracking channels.

The sum or range signal is composed of signals from all four feed horns added together in phase. Since the radar's range system is only interested in the presence of the target in the beam, and not in the target's relative position within the beams, the sum of all the energy received is used in ranging to insure maximum detection capability. The sum signal is also used as a phase reference for the amplitude difference signals which are the elevation and traverse error signals. The sum signal is obtained in the following manner. The energy from horns A and B is applied to the ring HY-2. These signals are 180° out of phase with each other. (Remember that the waveguides are different between these two horns and the ring.) Now, according to rule 4: the output of the Σ arm will be proportional to the sum of the amplitudes of the input signals, (A + B). The energy from horns C and D is applied to the ring HY-3. The action here is the same as for ring HY-2. The output of the Σ arm of HY-3 is C + D. The signals A + B and C + D are 180° out of phase with each other and are applied to the ring HY-1. The output of the Σ arm of HY-1 is the sum of both signals or (A + B) + (C + D). This signal is sent to the radar receiver.

The traverse difference signal is made up of signals from horns A and C added in phase, and from horns B and D added in phase, but the latter combination of energy is 180° out of phase with the energy from A and C. The energy from horns A and B enters ring HY-2 and, in

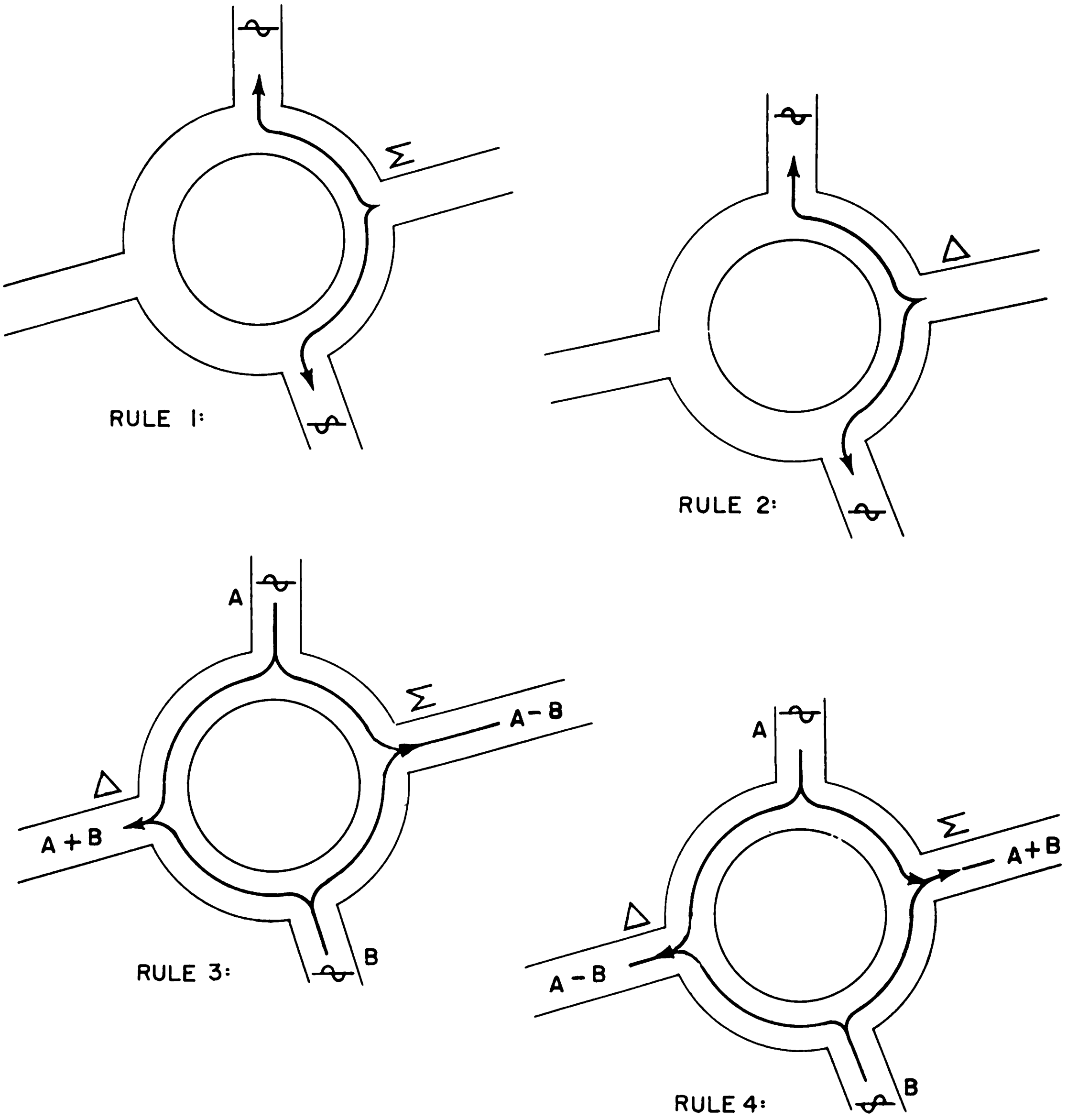

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Figure 8-12.—Hybrid ring junctions.

accordance with rule 4, the output from the Δ arm is the difference of the input signals. This signal A - B is sent to HY-4. The energy from horns C and D enters ring HY-3. The output from the Δ arm of the ring is C - D, which is sent to HY-4. The output of the difference arm of HY-4 is the difference between the two signals, which can be stated as (A + C) - (B + D). Note that this statement determines the difference in energy received from the left-hand horns, A and C, and from the right-hand horns, B and D. This signal is then sent to the traverse mixer in the receiver.

The elevation difference signal consists of the signals from horns C and D added 180° out of phase with A and B signals: (A + B) - (C + D).

This signal is arrived at by using the Σ arm of HY-2 and HY-3, and the Δ arm of HY-1. Note that this signal compares the energy received in the upper horns A and B with that received in the lower horns C and D. The signal is sent to the elevation mixer in the receiver.

The elevation and traverse difference signals are compared in the radar receiver with the sum or reference signal. The output of the receiver may be positive or negative pulses, the amplitude of which is proportional to the displacement of the target from the boresight (beam) axis. The polarity of the output pulses indicates the direction of the displacement. NOTE: The positive or negative output of the receiver is determined by the phase relationship of the ranging signal and the error signal. An example of how this phase difference may be detected can be found by a review of the magic-T coupler in chapter 6 of this manual. Of course if there is no angle tracking error, the output is zero.

This monopulse system provides direct amplitude comparison of the RF signals. Hence noise generated by the local oscillator and produced in the IF section of the receiver has less effect on the angle tracking system.

SYSTEM ERRORS

In any of the monopulse antenna systems, pointing errors can arise in two distinct ways. Phase or amplitude discrepancies in the received signals, which result from asymmetries

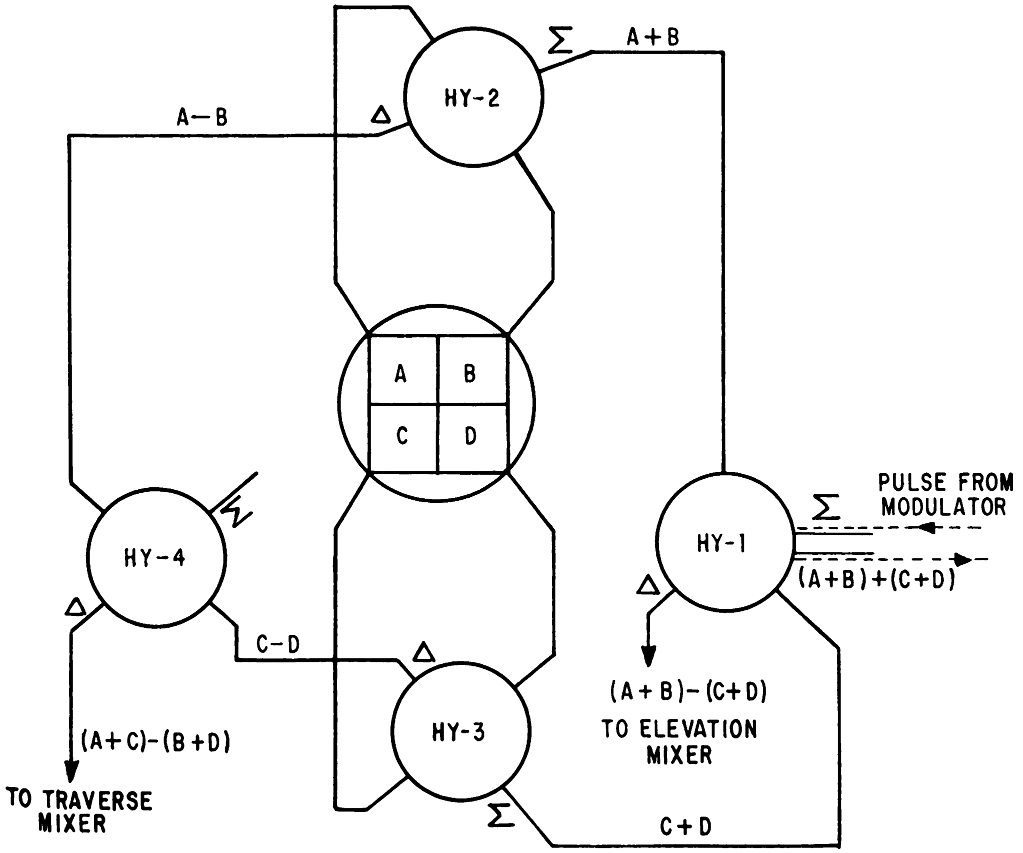

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Figure 8-13.—Microwave comparator.

in the feed structure from radome refraction, give rise to pointing errors. A second contribution to the pointing error arises from the combined effects of the radome error and the asymmetries and phase errors between the parallel receiver channels which are required in a monopulse system. Signal errors in phase or amplitude are always present to some degree, since the feed structure and the radome cannot be perfect. Similarly, phase discrepancies between receiver channels will generally be present. For satisfactory system performance, however, it is mandatory that both sources of pointing error be minimized; in fact, the design of IF amplifiers with satisfactory phase characteristics over a large dynamic range constitutes one of the major problems in a monopulse system.

A constant phase distortion causes the antenna pointing angle to deviate a fixed distance as long as the frequency is constant; however, at a constant frequency, variations will occur in the errors introduced by amplitude distortions in combination with phase errors between receiver channels.

Some shift in itself is not detrimental (as long as the frequency is constant), since it merely defines a new pointing axis. The position of the new axis, however, varies with frequency, and it is the shift of the pointing axis with frequency which is important. The phase error between feeds may result from structural asymmetries in the feed, or it can result from radome effects as well. Since the phase errors caused by the radome vary as the antenna scans, a variable shift in pointing axis then results, even with a fixed frequency. The major source of error for both phase and amplitude comparison monopulse systems are in the feed system as follows:

1. For the phase comparison system the primary errors are phase errors, and secondary errors are amplitude errors (in front of the sum and difference circuits).
2. In the amplitude comparison systems the primary errors are amplitude errors and secondary errors are phase errors.
3. Both systems experience phase errors between receiver channels.

PULSE EXPANSION AND COMPRESSION

Within the past few years, an amazing and powerful radar technique called pulse compression (nicknamed "Chirp Radar") has been incorporated in all types of radars. Pulse compression is possibly the most significant new advance in radar techniques in many years. It can improve a radar's performance by a factor of possibly several hundred. There appears to be no limit in sight to its possibilities. It is finding use in long range search, missile control, fire control, weather observation, aircraft traffic control, and mapping radar, and many more. Frequently, computers are used to display the returned target information using standard target symbols rather than displaying conventional video on a PPI type indicator. These symbols depict target position, size, type aircraft, and movement of the target. Generally, the radar is computer controlled.

ADVANTAGES

Some of the advantages which are discussed in this section are extended range with improved range resolution, height finding capabilities, immunity from ECM jamming, and an increased signal-to-noise ratio.

Extended Ranges

One important factor in any radar's maximum range is the envelope power. Envelope power is found by multiplying the pulse width times the peak power.

A typical search radar has a pulse width of 2 μsec and a peak power of 2.5 megawatts. This will produce an envelope power of 5 watts/sec. A typical pulse compression radar will have a pulse width of 10 μsec and peak power of 1 megawatt which will produce an envelope power of 10 watts/sec. Since range is partially determined by the transmitter, this will give us the possibility of an increased range over the conventional pulse radar.

Improved Range Resolution

Range resolution is the minimum distance which two targets must be separated to appear as two separate displays on a scope. This separation is largely determined by the pulse width of the echo being returned to the receiver. In our typical conventional radar with a 2-μsec pulse width, range resolution would be 1,000 feet. In the pulse compression radar, the 10-μsec returned pulse is compressed to 0.1-μsec before being applied to the receiver. Therefore, the range resolution is 0.1 x 500 or 50 feet.

This improved range resolution is accomplished without affecting maximum range because the envelope power is not changed.

Height Finding Capabilities

The theory employed by pulse compression to determine height is based on the ability of the radar to receive multiple path returns from a single target. With sufficient power, receiver sensitivity, and range resolution, the system can distinguish between three echo returns. (See fig. 8-14.) By measuring the time difference of the three returns and comparing the altitude of the radar transmitter, the computer can determine the target altitude. Only the pulse compression radar has both the power and range resolution necessary for this type of altitude determination.

ECM Deception

The pulse compression radar depends on the phase and frequency characteristic of the transmitted pulse to determine whether or not to accept a returned signal. If the phase and frequency do not match the transmitted pulse, compression will not take place and the signal will not pass through the receiver.

Signal-To-Noise Ratio

Due to the response of the matched filter to the definite phase and frequency characteristic of the transmitted signal, and the attenuation of other signals, the pulse actually applied to the receiver has a signal content much higher than its content of random noise. The signal-to-noise ratio of the system will be improved by a factor equal to the compression ratio over conventional radar.

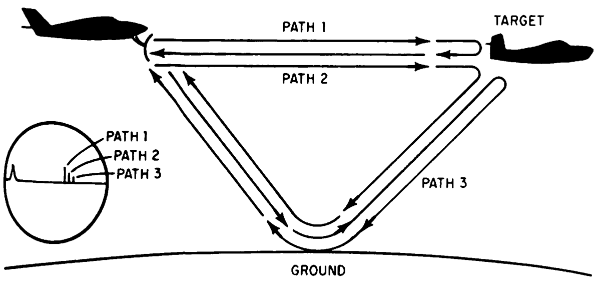

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Figure 8-14.—Multiple echo paths.

Target Velocity

Target velocity can be rapidly determined by the use of a computer and sideband inversion. If a signal receives up Doppler, after sideband inversion the shift will appear as down Dopper. By shifting the local oscillator frequency above and below the returned echo on alternate pulses, the Doppler can be changed from up to down alternately with each transmitted pulse. This will produce a shift equal to twice the normal Doppler shift and will make it possible to determine target velocity in a time equal to two PRT. This principle could be easily incorporated. Sideband inversion is explained in detail later in this discussion.

PULSE EXPANSION

The pulse expansion operation will utilize a 0.1-μsec pulse and expand it to 1-μsec. Then stagger delay (frequency) the 1-μsec pulses to form a 10-μsec chain of pulses for transmission. The overall operation is to generate a 0.1-μsec pulse and, after expansion, transmit a 10-μsec pulse.

Spectrum Generation

RF energy is generated by a Coherent Master Oscillator (COMO) which is gated with a square wave of the desired time duration. For discussion purposes we will use a COMO with a center frequency of 100 MHz which is gated for 0.1-μsec at a PRF of 300 Hz. When this pulse is produced, it contains not only the basic frequency, but also many other frequencies within a spectrum as illustrated in figure 8-15. While the difference between each frequency is determined by the PRF, the pulse width determines the bandwidth and therefore the number of frequencies within the spectrum is controlled by both PRF and pulse width.

In figure 8-15 the frequency which has the largest amplitude is the resonant frequency of the signal source by means of which this spectrum was created. Numerous other frequencies result on either side of f_o. Those above f_o will be f_o plus one PRF, f_o plus 2 PRF's etc. At this rate, numerous different frequencies

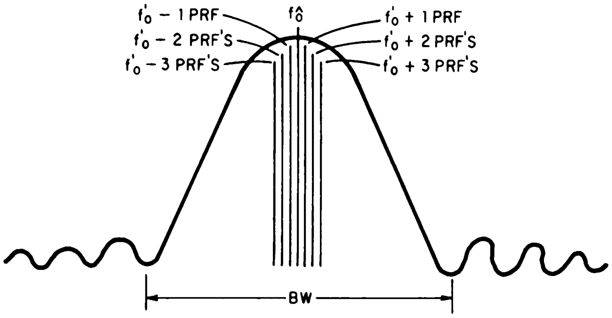

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Figure 8-15.—COMO output.

are present, each 300 Hz apart, and each smaller in amplitude as these frequencies approach the upper bandwidth limit.

Those below f_o will be f_o minus one PRF, f_o minus 2 PRF's, etc. At this rate numerous different frequencies would be present, each one lower in frequency by 300 Hz, and each one lower in amplitude as the lower bandwidth limit is approached.

Since the COMO is gated for 0.1-μsec of time, the COMO will generate a spectrum with a bandwidth of 20 MHz. Bandwidth is determined by dividing the pulse width into 2. NOTE: In order to receive and to reproduce satisfactorily rectangular pulses equal in amplitude to the noise voltage, the receiver bandwidth in Hz should be approximately 2, divided by the pulse width in seconds. Therefore, a 0.1-μsec pulse width will generate a 20 MHz spectrum bandwidth. Because each different frequency between the bandwidth is 300 Hz apart, over a 20 MHz bandwidth, there are 66,666 different frequencies contained in this frequency spectrum.

Matched Filters

For this discussion our matched filter will consist of 10 channels. Each channel will have one or more amplifier (one of which must be tuned) and a delay line as shown in figure 8-16. Each channel has individual gain and frequency controls with a bandwidth of 1MHz. The amplifiers are tuned to successive frequencies 1MHz apart so that their response curves overlap at their half power points as shown in figure 8-17. The entire filter band pass will be 10MHz from the center of the above described spectrum. The filter will now respond to 33,333 different frequencies with each channel responding to 3,333 different frequencies. The 10 sections with their respective delay lines are connected with parallel inputs and all outputs connected to a summing amplifier to produce a single output.

The entire frequency spectrum bandwidth (20MHz is applied to the input of each of the 10 channels through the delay line (all except channel 1 which has no delay line).

Each of the 10 channels is tuned so as to cover only a small part of the total frequency spectrum. Since there are only 10 channels, each with a bandwidth of 1MHz, only one-half of the overall spectrum is covered. Therefore, one-half of the spectrum is not passed through the matched filter because it is not within the half power points of any of the 10 channels.

This is necessary because the amplitude of the different frequencies is too great between the maximum and minimum. If the frequencies outside of the channel spectrum half power points are rejected, the amplitude difference between f_o and f_1 or f_2 is now only 3 db. This allows the gain of the channel to be within practical limits.

As was previously determined, the numerous different frequencies within the entire spectrum bandwidth were separated from each other by 300Hz, and since the overall bandwidth was 20MHz, there were 66,666 different frequencies. The matched filter is tuned to react to only half of the overall bandwidth, so the filter will receive only 33,333 different frequencies. This is in turn covered in 10 different steps by the 10 filters, so each individual filter will receive only 3,333 different frequencies. For ease of explanation, only 3,300 frequencies will be used in the remainder of this chapter.

EFFECT OF A TUNED AMPLIFIER ON FREQUENCIES WITHIN ITS BANDWIDTH.—In a paralleled resonant tank circuit the voltage and current are in phase at f_o. At frequencies below f_o, the circuit appears inductive X_L, and voltage leads the current. The farther below f_o the frequency is, the more inductive the tank appears, and the greater lead voltage has over current. At f_1, the voltage leads the current a maximum usable amount.

To frequencies above f_o, the circuit will appear capacitive by the amount that the frequencies differ from f_o. Above f_o, the current leads the voltage by the amount of X_C to the frequency applied. At f_2, the current leads the voltage by the maximum usable amount. Since

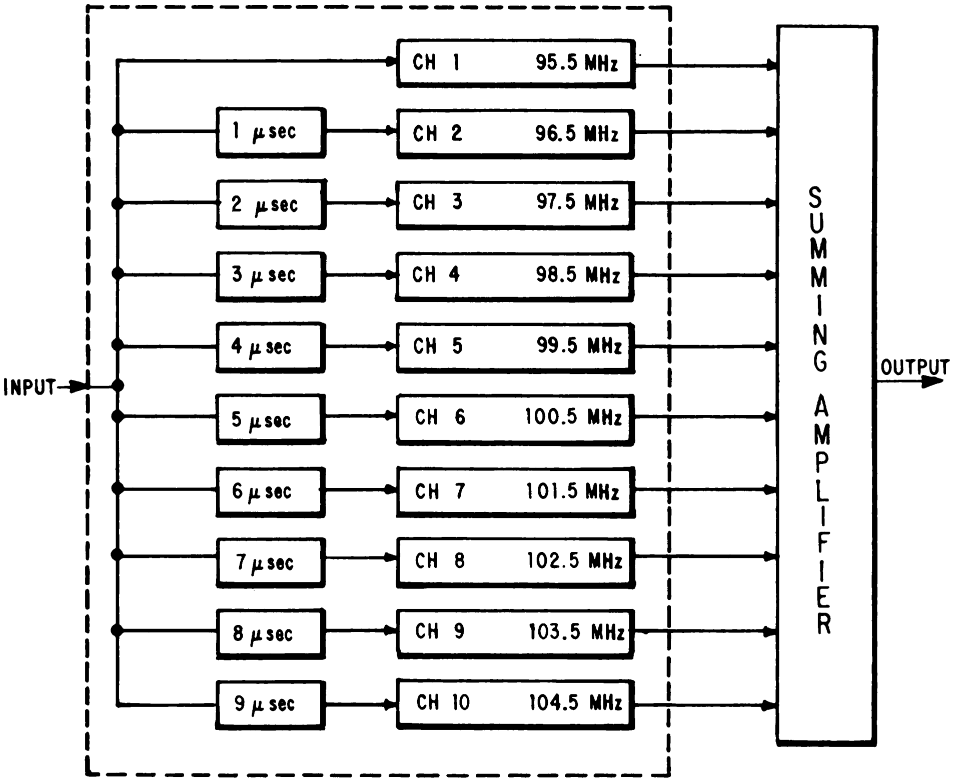

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Figure 8-16.—Matched filter assembly block diagram.

each tank circuit in the matched filter has a bandwidth of 1 MHz, and receives 3,300 different frequencies, approximately 1,650 of them will be above f_o, and 1,650 will be below f_o. To those above, the tank will appear capacitive. To those below, it will appear inductive. To the one frequency at f_o the tank circuit appears purely resistive.

The tuned amplifier is so designed that signal voltages are coupled out rather than signal current. To determine which signal voltages will be developed by the tank, first a reference must be used. This reference is the voltage and current which occur at f_o of the tank, and which are in phase because the tank is resistive.

The 1,650 frequencies, both above and below f_o, are applied to the tank circuit (tuned amplifier) at the same time. The voltage at the frequency f_1 of the tank will be leading the f_o current by the amount of X_L that this frequency sees.

Frequencies in between f_1 and f_o will be leading by a lesser amount because the tank circuit will appear less inductive to these frequencies. These voltages will have been advanced in phase (or time) in respect to the voltage at f_o of the tank.

The voltage of the frequency f_2 will be retarded in phase (or time) because the tank circuit will appear capacitive to that frequency. Before any voltage can be developed, current had to first begin to flow (because current leads voltage across a capacitive circuit). Voltages at frequencies in between f_2 and f_o saw less X_C, therefore, were retarded less.

The output from this tuned amplifier will be a series of signal voltages at 3,300 different frequencies with the lowest frequency (f_1) occurring first because it was advanced the most in time, and the highest frequency (f_2) occurring last because it was retarded the most in time.

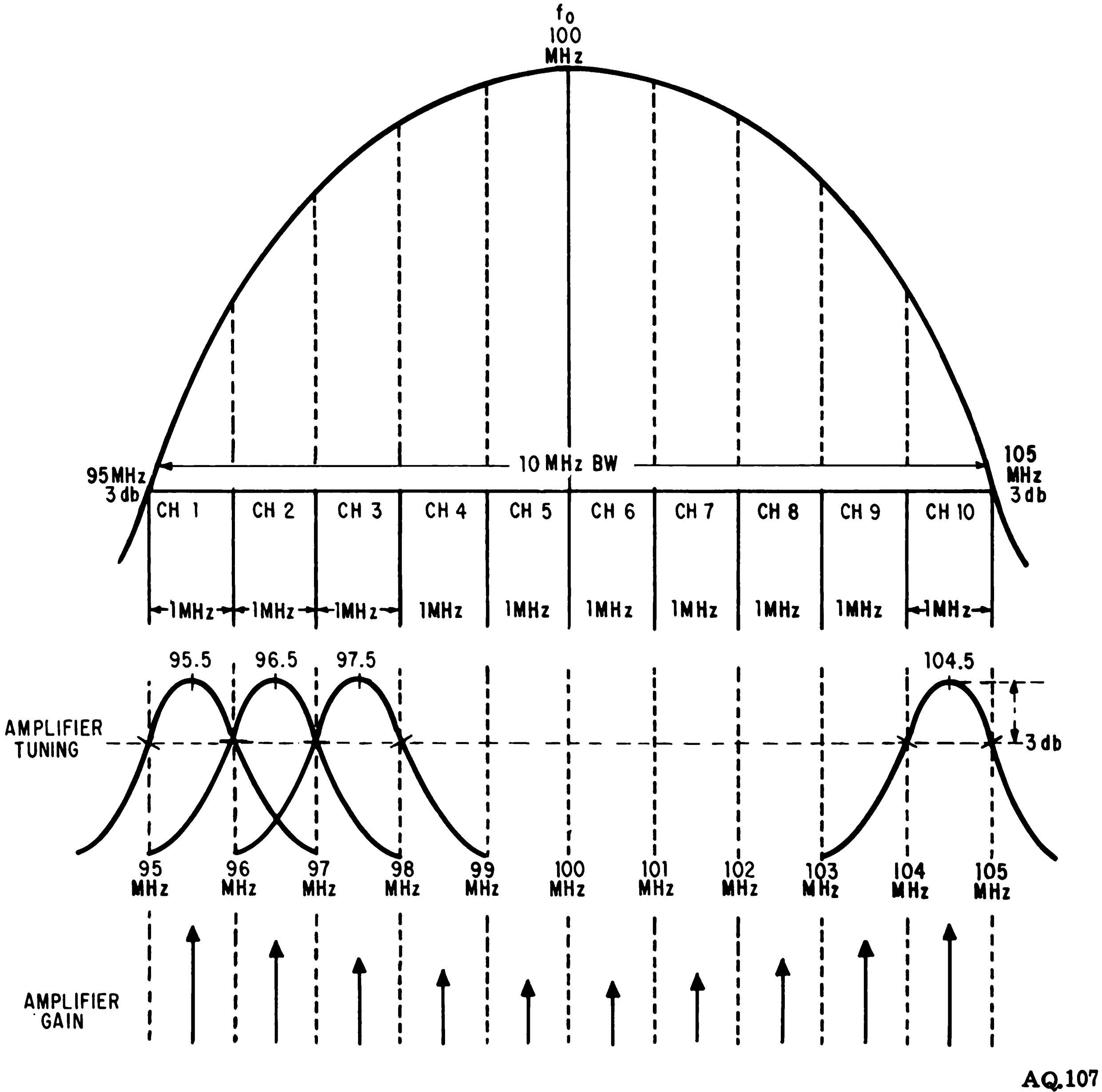

Figure 8-17.—All channel response curves.

The Q of the tank circuit will be selected so as to advance the voltage at f_1 by 0.5-μsec, and to delay or retard the voltage at f_2 by 0.5-μsec. THE TIME DIFFERENCE BETWEEN THE TIME WHEN THE FREQUENCY AT F_1 IS DEVELOPED AND THE TIME WHEN THE FREQUENCY AT F_2 IS DEVELOPED WOULD THEN BE 1-μsec. Since there are 3,300 different frequencies produced and coupled out of the tuned amplifier in a period of 1-μsec, the time delay between each of these different frequencies is 0.00031 μsec. As shown in figure 8-18, the first frequency to leave the tuned amplifier would be the frequency at f_1, and each 0.00031 μsec thereafter another frequency would be developed and coupled out until the frequency of f_2 is developed 1 full μsec later.

Since frequency is the reciprocal of time it can be seen that the output from each channel (1 μsec in time) will be 1 MHz wide in frequency.

What has been done is to take 3,300 different frequencies, each one in phase, and time

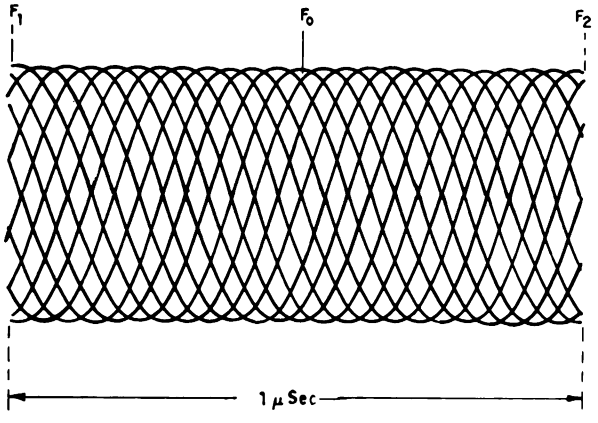

Figure 8-18.—Individual channel frequency output (expansion).

delay or time advance each one by a different amount. This process has created a waveform which begins to appear as a linearly swept FM wave, and is called time dispersion or phase dispersion.

COMBINED OUTPUT OF THE MATCHED FILTER.—As shown in figure 8-16, the entire frequency spectrum is applied to the input of each of the 10 filter channels simultaneously, but through a delay line for channels 2 through 10. This means that channel 1 will receive its input at the instant the spectrum is applied to the input of the filter; however, channel 2 will not receive its input until later in time due to the delay line. Channel 3 will receive its input still later in time than channel 2. This process will continue so that channel 10 will receive its input last because the delay line in its input offers the largest amount of delay.

Channel 1, since it received the frequency spectrum first, will produce an output first. Channel 1 is tuned to 95.5 MHz, and has a 1 MHz bandwidth, so it will produce in its output only that part of the spectrum from 95 MHz to 96MHz. The frequency to first appear at the output of channel 1 will be the lowest frequency within the bandwidth of the tuned amplifier. This is because the lowest frequency receives the greatest phase or time advance because of X_L of the tank circuit at that frequency. The last frequency to leave channel one will be the highest frequency within its bandwidth. This frequency receives the most time or phase delay because of X_C of the tank circuit to that frequency. Each of the remainder of the 3,300 frequencies will be either advanced or retarded by a lesser amount, so that the time required for channel 1 to reproduce all 3,300 frequencies will be 1 μsec.

As channel 1 is finishing its output waveform, channel 2 is just receiving the spectrum at its input (because the spectrum was delayed 1 μsec by the delay line). Channel 2 is resonant to 96.5 MHz, has the same 1 MHz bandwidth, and will reproduce that part of the spectrum from 96 MHz to 97 MHz. The lowest frequency within the bandwidth of channel 2 will be reproduced first because it receives the greatest advance by X_L. The highest frequency will be reproduced last because it is delayed by X_C. Channel 2 will require 1 μsec to produce its full 1-MHz output. Two μsec in time have now elapsed.

As channel 2 finished producing its output, channel 3 receives the frequency spectrum at its input through the 2-μsec delay line. Channel 3 picks up in frequency where channel 2 left off and provides another 1-MHz part of the output for a period of 1 μsec.

This process continues until channel 10 receives the frequency spectrum at its input after being delayed by the 9-μsec delay line. It then produces the tenth part of the total output waveform which is resonant from 104 MHz to 105 MHz. It is also 1 μsec wide.

The lowest frequency of channel 1 (95 MHz) is produced, and 10 μsec later, the highest frequency of channel 10 (105 MHz) is produced. This is shown in figure 8-19.

Each of the 10 channels output waveforms will be combined in the summing amplifier to produce the waveform shown in figure 8-19. This waveform sweeps a 10-MHz band of frequencies during a time of 10 μsec with a linear change of 1 MHz/1-μsec. This type of waveform is called a linear frequency modulated pulse. The matched filter which produces this type of waveform is called a LIFMOP filter being coined from LInear Frequency MOdulated Pulse. This LIFMOP waveform contains approximatedly 33,000 different frequencies, each one being in a very definite time and phase relationship to the others.

The output from each channel must be equal in amplitude. To insure equal amplitudes from each channel, an oscilloscope is connected to observe the output of the summing amplifier.

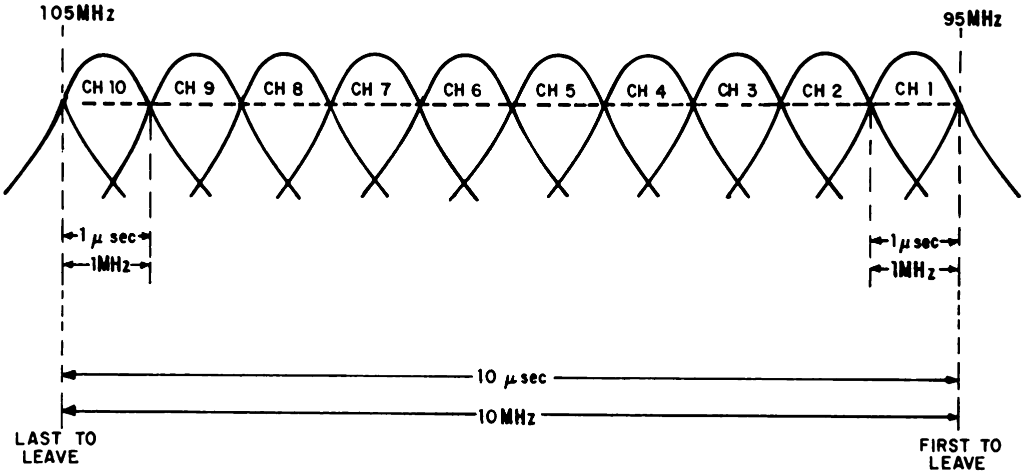

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Figure 8-19.—Summing amplifier output.

The amplitude adjustment (screwdriver adjustment) is set on each channel so that the output from each amplifier is equal in amplitude. With the oscilloscope connected to the same point, the frequency adjustment, (a technician's adjustment) is set so that the output of each amplifier coincides with the output of the amplifiers on either side of it with no interruption of the pulse. When any of the amplifiers are changed, both of these adjustments must be performed.

This LIFMOP waveform may be transmitted at these frequencies, or it may be passed through frequency converters to increase the frequency to whatever is desired to be transmitted. It will normally be amplified by several RF amplifiers prior to being transmitted. These RF amplifiers, of necessity, have a very broad bandwidth and linear frequency response to avoid any type of distortion of the LIFMOP waveform. The waveform shown in figure 8-19 leaves the summing amplifier with some amplitude variations. It is desirable that the transmitted waveform have no variations of amplitude. Normally, the waveform will be passed through a limiter prior to transmit to remove these amplitude variations.

The transmitted pulse will be rectangular, swept in frequency over 10 MHz, and 10 μsec in duration. It is composed of the combined outputs of all 10 filters.

PULSE COMPRESSION

This operation is basically the inverse of pulse expansion. That is when a 10-μsec target return is received, it is compressed so that the receiver output is a 0.1-μsec echo.

Echo Return from a Target

For discussion purposes assume that a target is located a distance from the receiving antenna so that a 100-μsec of travel time will be required for the return echo to reach the receiver antenna. The lowest frequency was the first to leave the transmitter, and the first to strike the target; thus, the lowest frequency will be the first to be picked up by the receiving antenna. (It will be returned 100-μsec after it strikes the target.) The highest frequency transmitted did not leave the transmitter until 10 μsec later. It did not strike the target until 10 μsec after the lowest frequency struck the target. Therefore, it was not returned to the receiving antenna until 10 μsec after the lowest frequency was received. Refer to figure 8-20.

It can be seen that a definite time versus frequency relationship exists during the 10 μsec that the returning echo is felt on the receiver input. At any time, the frequency can be determined and, therefore, which channel is receiving a signal. For instance, at T_0 plus 106 μsec, the frequency which will enter channel No. 6 is just arriving at the receiver antenna. This means that the frequencies affecting channels 1 thru 5 have already arrived, and channels 7 thru 10 are yet to come.

If the returned echo is applied to the matched filter as it is now (lowest frequency first), by action of the L and C of the tanks, the filter

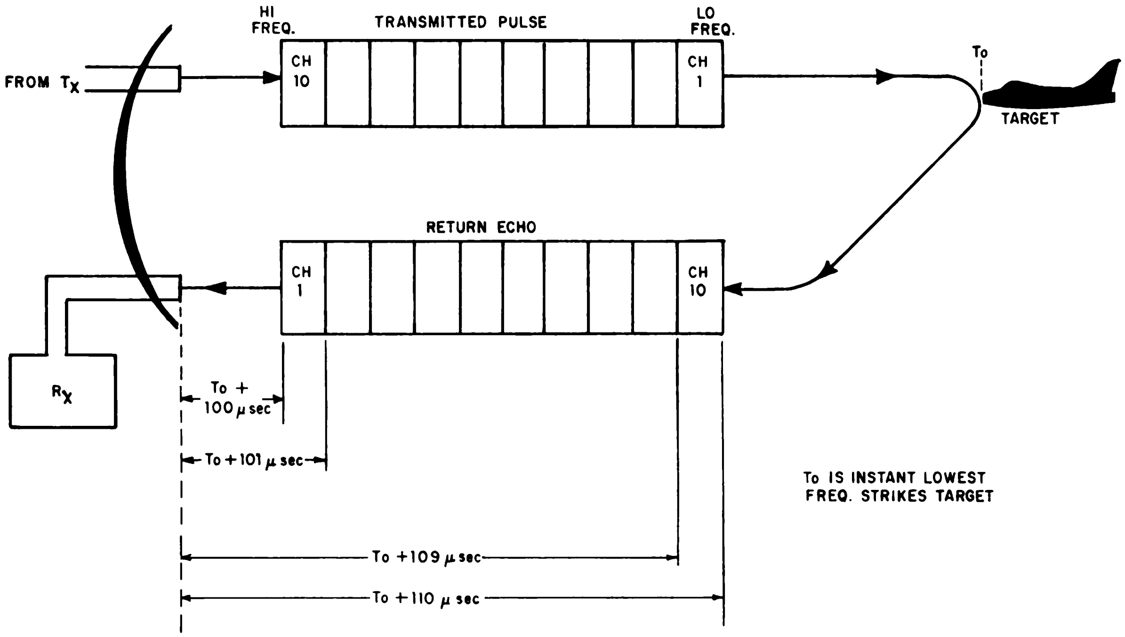

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Figure 8-20.—Time function of transmitted pulse.

would tend to expand the signal again, rather than compress it as is desired. FOR THE PULSES TO BE COMPRESSED, THE FREQUENCY RELATIONSHIPS MUST BE REVERSED. That is, the returned echo must be turned around so that the highest frequency enters the matched filter first, and the lowest frequency enters last, or 10 μsec later. This is easily accomplished by sideband inversion.

SIDEBAND INVERSION.—Sideband inversion is a process of inverting the frequencies contained in the upper and lower sidebands during the process of frequency conversion. This process occurs any time the local oscillator is tuned ABOVE the frequency to be converted, and the DIFFERENCE frequency is selected. (See fig. 8-21.)

NOTE: The reader should be aware that the frequency values used in figure 8-21 are arbitrary values and were selected only to illustrate sideband inversion.

From figure 8-21, it can be seen that when the upper sideband (101 MHz) passes through the mixer, the difference frequency produced is 9 MHz. When the lower sideband frequency (99 MHz.) is converted, the difference will be 11 MHz. Thus, the highest incoming RF produces the lowest difference frequency, and the lowest RF produced the highest difference frequency. In the case of the pulse compression radar under discussion, the returned echo is passed through a frequency conversion stage for the purpose of sideband inverting the frequencies. The lowest frequency which was

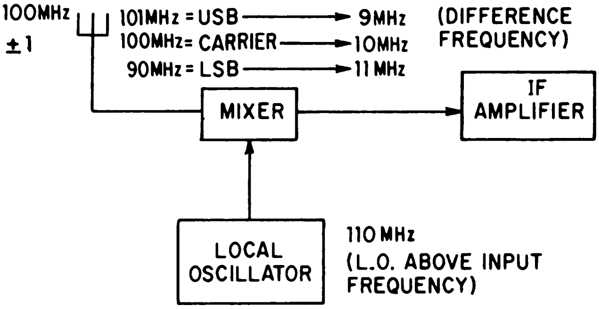

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Figure 8-21.—Sideband inversion block diagram.

ıt returned will become the highest frequency ɛr sideband inversion (95 MHz will emerge 105 MHz). The highest frequency (105 MHz), urning last will emerge from the mixer as MHz. Because of this process, the entire quency content of the returning pulse will reversed. After this inversion, the echo now ready to be applied to the matched fil-s for pulse compression.

ion of Matched Filter the Returned Echo

The returning pulse, AFTER SIDEBAND ERSION, is once again applied to the par-el inputs of all 10 matched filter channels. e difference between the input to the matched er, now on the pulse compression function, l the input for the pulse expansion function transmit is that on pulse expansion, ALL quencies (each one in phase) were present EACH channel at the SAME TIME. But on se compression (or receive), the frequencies ive ONE AT A TIME, each one separated m the others by a small phase and time ference. The first frequency to arrive, at plus 100 μsec, is the highest input fre-ncy to the filter after conversion, and 10 c later, at T_O plus 110 μsec, the lowest ut frequency after conversion arrives at the er. It must be noted that as each individual quency arrives, it is present at the input to h one of the 10 channels simultaneously.

The highest frequency (after conversion), ng the first to arrive, is applied directly to matched input filter. Since this frequency within the bandpass of ONLY channel 10, will affect only channel 10. Before it can applied to the tuned amplifier of channel it receives a 9-μsec delay. Therefore, s frequency finally is present at the tuned plifier of channel 10 at T_O plus 109-μsec. r the next 1-μsec of time, all of the fre-ncies within the bandpass of channel 10 l arrive and be processed. The highest quency (105 MHz) at T_O plus 109-μsec, is ve the resonant frequency of channel 10 4.5 MHz), so the tank circuit appears capa-ive to that frequency.

The tank circuit has the same effect on quencies ABOVE its resonant frequency that has previously during pulse expansion—that it will delay these frequencies by an amount portional to the amount of capacitive re-ance the tank offers to that frequency. The 105-MHz signal, being the farthest away from the f_O of the tank, will be delayed the most (approximately 0.45-μsec).

The next frequency to arrive at the tank is slightly later in time and lower in frequency, and receives slightly less delay than did 105 MHz. When 104.5 MHz arrives (at T_O plus 109.5 μsec), the tank simply passes it exactly as it is. The rest of the frequencies within the bandpass of channel 10 are lower than the f_O and sees an inductive reactance. This advances these lower frequencies by an amount proportional to the X_L of the tank. The 104-MHz signal, the lowest frequency within channel 10's bandpass, sees maximum inductance and is advanced approximately 0.45-μsec. The end result is that the bandwidth of frequencies of channel 10 (which was 1 μsec wide) is compressed to 0.1-μsec, and comes out of channel 10 at T_O plus 109.45-μsec to T_O plus 109.55-sec. This is shown in figure 8-22.

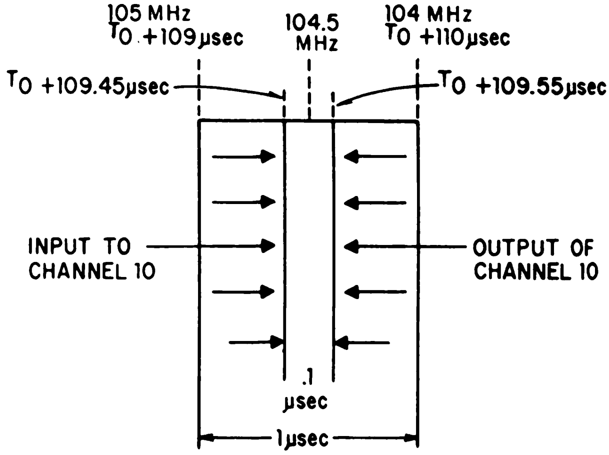

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Figure 8-22.—Individual channel compression.

The band of frequencies processed and compressed by channel 10 arrived at the receiver antenna from T_O plus 100-μsec to T_O plus 101-μsec. From T_O plus 101 μsec to T_O plus 102-μsec, the frequencies within the bandwidth of channel 9 will be arriving at the receiving antenna. To get to the tuned tank of channel 9, they must pass through the 8-μsec delay line. Then, at T_O plus 109-μsec, the first frequency for channel 9 (104 MHz) will arrive. This frequency is higher than the resonant frequency (103.5 MHz), so it will be retarded approximately 0.45-μsec, and will be reproduced in the output of channel 9 at T_O plus 109.45-μsec. The lowest frequency to channel 9 (103

MHz) sees maximum inductance and will be advanced approximately 0.45 μsec. Channel 9 will produce its output from T_O plus 109.45 μsec to T_O plus 109.55 μsec, or during the same time channel 10 was producing an output.

This process continues as each one of the channels receives its band of frequencies 1 μsec apart in time, but produces its output at the same time as each of the other channels. Finally, at T_O plus 109-μsec, the first frequency to pass through channel 1 arrives at the receiving antenna, and is felt directly on the tuned tank in channel 1 since channel 1 has no delay line. Channel 1 then produces an output at the exact same time as the previous nine channels.

COMBINED OUTPUT OF THE MATCHED FILTER.—The output circuit of each individual channel is fed into summing amplifiers where all 10 outputs are combined. Because each channel produces an output at exactly the same time, and for exactly the same time duration, all 10 outputs add directly, and appear at the output of the summing amplifiers as one pulse 0.1 μsec in duration. The entire 10-μsec return echo has been compressed to 0.1-μsec, and is now ready to be detected and sent to the indication devices.

The ratio between the pulse width of the transmitted pulse and the returned compressed target echo is expressed as the compression ratio. It is determined as follows:

$$\text{Compression ratio} = \frac{\text{pulse width of expanded pulse}}{\text{pressed width of com- pulse}}$$

The compression ratio of the radar being discussed is:

$$\text{Compression ratio} = \frac{10\text{-}\mu\text{sec}}{0.1\text{-}\mu\text{sec}} = \frac{100}{1} = 100:1$$

This expression is considered a figure of merit for a pulse compression type radar.

During this process of pulse compression, some apparent amplification occurs across the matched filter. This is because of the energy content and time duration of the returned echo. The 10-μsec pulse arrives with a certain volt/amps energy content, but it is compressed in time down to a pulse of 0.1-μsec. Assuming none of the energy content was lost across the matched filter, the same amount of energy must still be present in the compressed pulse. If the pulse width narrows, the amplitude of the compressed pulse will increase. This increase is the same as the compression ratio. In the radar under discussion the pulse is compressed by a ratio of 100:1, so the amplitude of the compressed pulse is 100 times larger than the amplitude of the received target return, and still contains the same energy content.

It must be noted that in a practical radar using pulse compression, it is very difficult to get the returned energy compressed back to the same pulse width that was used in the pulse expansion sequence. As previously, there are many thousands of frequencies, each different by one PRF, in the transmitted pulse. Each of these frequencies bears a very definite time/phase relationship to each other. To compress the returning echo back to the original pulse width, each one of the frequencies must be present, and must still bear the exact same time/phase relationship that it did upon leaving the transmitting antenna. Due to atmospheric conditions and waveguide vibration, some phase modulation occurs between pulse expansion and pulse compression. Some of the frequencies will be changed, so it will not be easy to reconstruct the original pulse. In the radar under discussion, typically the 10-μsec returned echo is compressed into a 0.2-μsec pulse, for a compression ratio of 50:1. This means that if the entire energy content is maintained across the filter, the amplitude of the compressed target video would be 50 times larger than the amplitude of the returning echo.

SIGNAL-TO-NOISE RATIO

The noise which might exist in the band of frequencies covered by the radar are at random frequencies and bearing random phase relationships to each other, and to the returning target echo. Any of these frequencies which exist within the bandpass of the matched filter passes through the filter, but are not affected by the filter. That is, they are neither expanded nor compressed because of their random relationship, so they emerge at the same amplitude at which they went in while the return echo emerges enlarged in amplitude by the amount of the compression ratio. Radars using pulse compression are generally considered to have an increase in the signal-to-noise ratio across the matched filter approximately equal to the compression ratio. This is in addition to the signal-to-noise ratio rease which might be gained by using suitable eiver input amplifiers.

M CONSIDERATIONS

As was previously stated, it is very difficult jam a pulse compression type radar. This primarily because of the characteristics of matched filter. To overcome the target video se jammers would have to produce enough se signal so that the noise at the receiver enna would be greater than the returning get echo by the amount of the compression io. This is easily eliminated by insertion of cuits between the antenna and matched filter ich automatically reject abnormally large nals. This method is currently in use in tain long range search radars in operation h the fleet. Repeater jammers, to override actual target return, would have to generate spectrum containing exactly the same fre- encies, each bearing the exact same phase and e relationships as that of the transmitted se. Even if this were possible (some types ECM equipments simply amplify whatever ir antennas receive), the ECM signal would rejected since it would be larger in amplitude n the valid received target return. This peater jammer could have no more delay ween the time it received the transmitter's nal and the time that it retransmitted this me amplified signal than the time duration of compressed pulse as it comes out of the tched filter. When the delay is greater than pulse width of the compressed pulse, the lication device (computer) would see two stinct returns. One would be the target, and other would be the ECM signal. Even if the lay was less than the pulse width of the com- essed pulse, the computer would still see the get return first, then a sudden increase in plitude as the ECM signal came through. The mputer would automatically reject ECM turn, but would see the target return. Chaff mming is easily countered by the incorporation circuits which reject abnormally slow moving gets such as chaff, corner reflectors, balloon rne devices, and etc.

To further increase the difficulty in jamming pulse compression type of radar, the PRF uld be made to vary at random rate. This will use each and every frequency in the trans- tted pulse to change slightly each time the nsmitter fires. Unless the returning echo ntains exactly the same frequencies that were just transmitted, the matched filter will reject them.

PULSE-DOPPLER RADAR

Because of the speeds that newer aircraft are traveling, the radar system must give accurate range resolution. It must also have the ability to distinguish moving targets from fixed targets and to determine the direction of movement in the case of moving targets. Pulse radar systems that have these capabilities are known as MTI (moving target indicator) and AMTI (airborne moving target indicator). The basic MTI system is discussed in Basic Electronics, Vol. II. This discussion is centered around a basic AMTI system.

Airborne moving target indication (AMTI) becomes desirable from two standpoints: First, it allows only moving airborne targets to be presented on the scope; and second, it reduces the sea clutter return on the scope. The requirement for a satisfactory AMTI is one of long standing, and one that is even more pressing now with the advent of automatic radar data processing devices.

DESCRIPTION

The function of the AMTI system is to cancel or attenuate signals received from fixed targets, while permitting signals from moving targets to be amplified and sent to the indicating system. The AMTI system does this by comparing the phase of each returning target echo from the preceding transmitted pulse. In the comparison process, signals with like phase (from fixed targets) are canceled, and signals with unlike phase (from moving targets) leave an uncanceled residue.

Due to the Doppler effect, the frequency of a signal reflected from a moving target is different from the transmitted frequency. In a radar system, the actual frequency changes are minor due to the fact that aircraft velocities are very small compared to signal velocity. This makes it impracticable to make a direct frequency comparison between the transmitted and received signals. Instead, a method of phase comparison is used to determine the pulse-to-pulse phase shift of returning signals.

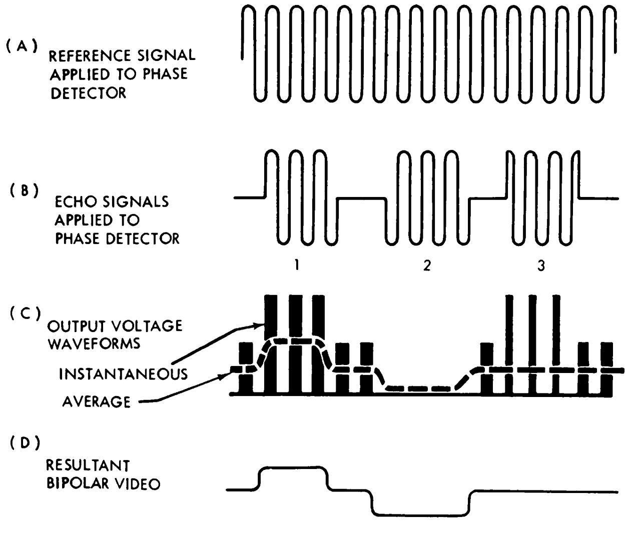
Figure 8-23 illustrates the phase detection principle involved.

In this diagram, if you assume that the reference signal (A) is held constant with the starting phase of each transmitted pulse, it becomes apparent that echo signal (B) will give the same resultant video (D) for successive pulses from the same stationary targets. If, however, one of the echoes in (B) is a reflection from a moving target, a phase shift will take place between successive pulses (because of the Doppler effect), and the resultant video (D) will have greater or less amplitude. This phase detection principle is valid for an AMTI system only under the condition that the reference signal (A) assumes the same starting phase as each successive transmitter pulse.

PRINCIPLES OF OPERATION

There are two basic types of moving target indication systems—coherent and noncoherent. The coherent system depends upon an internally generated signal from a coherent oscillator. The noncoherent system depends upon ground clutter to supply its reference.

In a true coherent system, a signal from a coherent oscillator is locked in with the transmitted pulse to provide a reference signal, and a phase shifter is employed to compensate for the effect of the airborne radar's motion. This phase shifter must be servoed to the aircraft's velocity and the antenna azimuth.


(A) REFERENCE SIGNAL APPLIED TO PHASE DETECTOR
(B) ECHO SIGNALS APPLIED TO PHASE DETECTOR
1
2
3
(C) OUTPUT VOLTAGE WAVEFORMS
INSTANTANEOUS
AVERAGE
(D) RESULTANT BIPOLAR VIDEO

SIGNAL 1. IN PHASE WITH REFERENCE SIGNAL
SIGNAL 2. 180° PHASE SHIFT FROM REFERENCE SIGNAL
SIGNAL 3. 90° PHASE SHIFT FROM REFERENCE SIGNAL

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Figure 8-23.—Phase detection of returning echo signals.

In the noncoherent type of moving tar indication, the return from either ground clut or a fixed target is used as a reference sig These signals will appear to remain constan amplitude, from one transmitted pulse to next, where the moving target is consta changing in amplitude.

The AMTI feature of the search radar designed to display moving surface targets wh suppressing the display of fixed targets ground return.

The AMTI, as used in the A-6 type aircr is a noncoherent type which requires that target must have motion with respect to gro clutter or permanent echoes with the same ra in order to be processed as video on Bombardier/Navigator's (B/N's) Direct V Indicator (DVI) and the Pilot's Horizontal D play System (PHD).

The search antenna radiates RF energy the form of a pulse which illuminates an a that is determined by the antenna beamwidt azimuth (1.4°) and the pulse width in range (microseconds or 200 feet).

The RF energy reflected from the scan area is composed of a large number or rando phased components representing ground clutt permanent echoes, fixed targets, and mov targets.

It is characteristic of moving surface t gets to give returns which fluctuate in amplit above the normal ground return video. Mov target video will change amplitude from pulse to the next while fixed target and gro return video will appear to have maintaine constant amplitude in the time between puls The moving target video changes amplitude modulates) because the phase of the radiof quency return from the moving target is c stantly changing with respect to the RF ret from the surrounding ground area. The ret from moving target is of greater amplitude t the return from the surrounding ground ar Because the fixed target does not move relat to the ground, the amplitude of its radar ret remains constant from one pulse to the n The search AMTI detects the fluctuations moving target returns and amplifies and d plays them while suppressing or canceling constant amplitude returns of fixed targets ground.

In AMTI operation, the returning sea radar video is converted from an amplit modulated signal to a frequency modula signal, fed through both a delayed and a dir channel, and compared with the delayed signal from the previous pulse. By the manner in which the delayed and direct signals are compared, the frequency-stabilized fixed target and ground returns are canceled, and the changing frequency representative of moving targets is amplified. Since the delayed pulse must be delayed by a very exact amount, a specially stabilized 2,400 pulse per second trigger is generated for AMTI use. This is the search primary trigger. The search secondary trigger, available for the B/N's use, is not sufficiently stable to be used for AMTI operation.

The AMTI control on the B/N's control box controls the video mixer and allows the B/N to select full moving target video, regular search radar video, or any mixture of the two. The design of the AMTI circuits is such that the return from a moving target is enhanced by being compared with, or referenced to, the ground or fixed target return. Therefore, in the absense of ground or fixed target returns, moving targets are treated as fixed targets and are suppressed or completely canceled. It could be expected that a heavier ground return would optimize the moving target indications; however, rock outcrops and hard targets are usually not fully canceled and tend to distract or confuse the B/N. If doubt exists as to whether a return is displayed as a moving target return or a fixed target return, the audio circuitry of the track radar can be helpful in determining whether the target is moving or fixed, and in the case of a moving target, the relative size and/or speed may be determined by the pitch (frequency) of the audio.

The amplitude fluctuations caused by a moving target are only detectable for the range component of target movement. For this reason, a target that is moving on a line perpendicular to the aircraft heading will not be detected. The detection range of a given moving target will increase as the aircraft approach heading approximates the fore-and-aft axis of the target movement (head-on or tail-on approach). The relative approach angle (angle-off) between aircraft and target becomes most critical with slow moving targets. For example, a 10-mile per hour pickup truck and a 4-mile per hour road grader, traveling the same road, could both be detected at the same range on a 0° angle-off run, but the detection range for the

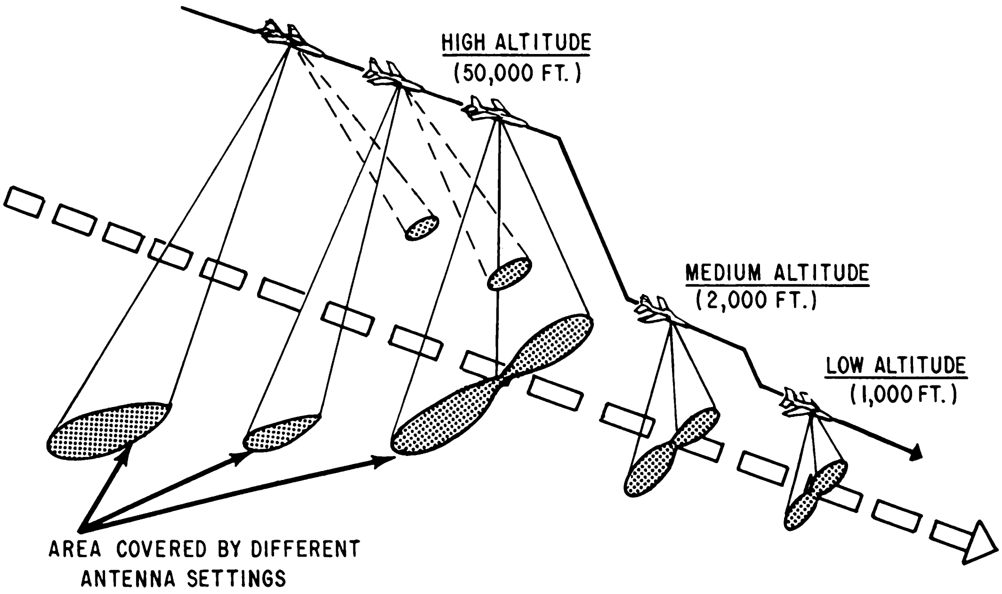

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Figure 8-24.–SLR antenna coverage.

road grader would be half that of the truck on a 10-mile angle-off run.

Since the AMTI operates on the principle that a moving target causes amplitude fluctuations above the normal ground return, the AMTI circuits are extremely noise and jitter sensitive. Radar receiver noise or magnetron jitter can render the AMTI virtually useless. Experience has shown that a radar which the B/N believes to be excellent in all other respects can, in fact, be practically useless for AMTI operation due to the noise. The only check the B/N can make is to check automatic frequency control (AFC) operation against manual frequency control (MAN) for maximum radar range or best land/water contrast. If MAN is significantly better than AFC, it should be used. The real difference in above average AMTI lies with the quality of the radar maintenance. For first-class AMTI, the maintenance crews must periodically look at the radar magnetron for jitter, and closely monitor the radar receiver for clean noise-free video. Additionally, the technicians should be alert to any indication of progressive rada degradation provided by B/N debriefing.

SIDE-LOOKING RADAR

The surveillance and mapping of large area and the capability of providing data which permits rapid and accurate identification, locatior and interpretation of all important feature within the areas surveyed are of vital importance today. Airborne radar's ability to operat during night or day under adverse weathe conditions with the mobility and range of a airborne platform make radar ground mappin systems ideal. Side-looking radar (SLR) systems have proved to offer many advantage over other radar ground mapping systems

PURPOSE

The side-looking radar system provide photographic data which is displayed by reflecte microwave energy rather than by reflected ligh

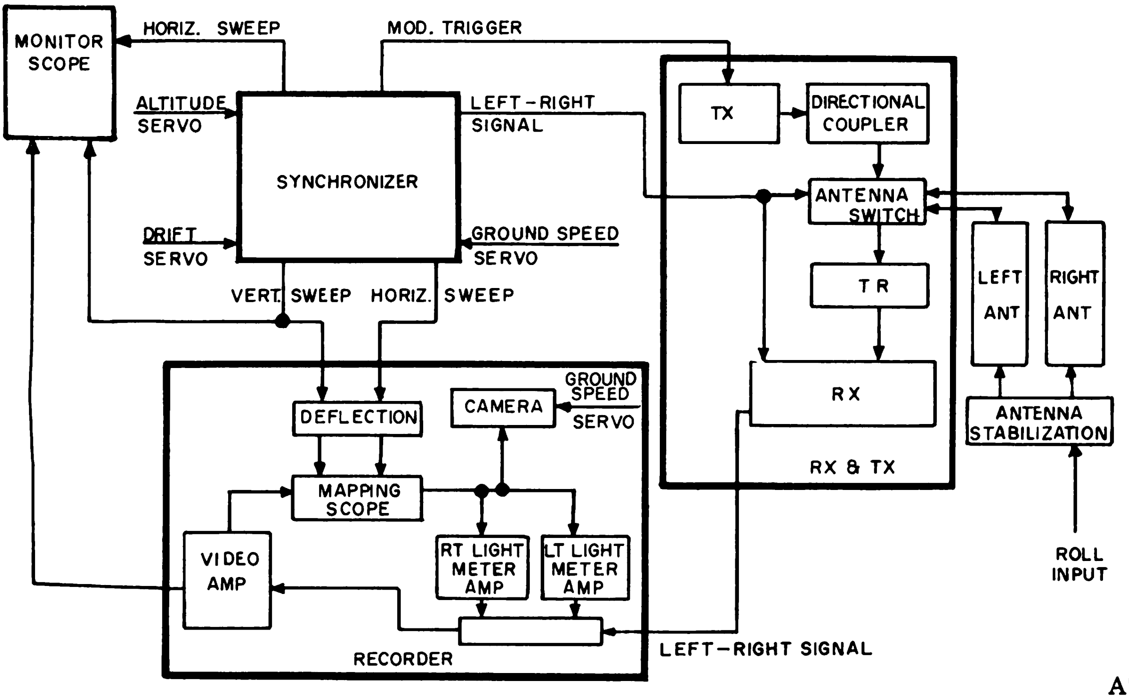

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Figure 8-25.-SLR block diagram.

Although the film resolution of SLR photographs does not compare with that of standard aerial photographs, the SLR photography is capable of displaying data which would not appear on a standard photograph. An example of this would be detection of a hard target (gun emplacement) under camouflage material where the reflection of microwaves would show up clearly on the recording. The system also provides a map of the terrain which can aid in filling questionable gaps on photographic information. Because SLR is "side-looking," it has an inherent security-against-detection advantage when compared with forward looking radar since the radiation from the parent aircraft will not be detected until the aircraft is passing the target.

PRINCIPLE OF OPERATION

Continuous mapping of terrain on both sides of the aircraft is accomplished by a pulse type radar system. Each SLR antenna directs a radar beam toward the ground with the reflected energy providing one dimension of the map. Forward motion of the aircraft provides the second dimension. An SLR antenna is mounted on each side of the aircraft fuselage or in an integrated package which mounts below the fuselage. Generally, higher altitudes provide coverage of larger areas but with less detail. (See fig. 8-24.) Manual antenna control gives the operator the choice of looking directly below or out away from the aircraft.

Figure 8-25 is a basic block diagram of an SLR system. The synchronizer unit receives corrective inputs from the altimeter, drift, and groundspeed servos. The outputs consist of a trigger signal to the transmitter; a left-right signal to the antenna switch, the receiver AGC, and the recorder amplifier; and sweep signals to both scopes. The altitude information is used to determine which pulse width is used, sweep timing, and receiver gain. This information is permanently recorded in the recorder system for proper interpretation of map information. The groundspeed information is used to control sweep speed, receiver gain, and recorder film speed. As aircraft speed is reduced, the sweep speed is reduced and the receiver gain must be decreased to prevent blocking of the scope presentation. The film speed is also reduced so that film length will correspond to distance covered. Drift information is used to correct the sweep angle so that the presentation is of the area perpendicular to the flight-path of the aircraft. The left-right signal controls the selection of antenna, receiver AGC, and recorder amplifier channel.

The transmitter is a pulsed magnetron which operates in the upper X or K bands with short duration pulses. The transmitter feeds into an antenna switching device which causes one antenna to be pulsed and then the other. The receiver is capable of responding to an extremely wide range of signal amplitudes and has a very wide bandwidth. It also has provisions for reproducing two separate antenna signals.

The recorder unit consists of a dual channel amplifier, a recorder scope, a recorder camera, and associated equipment. The scope is a dual presentation type with one for each antenna.

The SLR system has monitoring equipment which allows an operator to control the system operation.

CHAPTER 9

RADAR CIRCUITS

The purpose of this chapter is to review the principles which determine the characteristics of radar circuits and to follow this review with a discussion of how these circuits are applied in a typical radar set.

Among the principles which should be reviewed before continuing with the present discussion are certain factors which affect radar performance. Such factors are carrier frequency, pulse width and PRF, power relation (relation between peak and average power), beam width, and scan rate. The choice of these arbitrary constants for a particular system is determined by its tactical use, the accuracy required, the range to be covered, the practical physical size, and the problem of generating and receiving the signal. Basic information concerning these factors may be found in Basic Electronics.

Three categories of basic circuits are discussed in the following paragraphs. These are timing circuits, sweep circuits, and transmitter circuits.

TIMING CIRCUITS

Timing or control is the function of the majority of the circuits in radar. Circuits in a radar set accomplish this function by producing a variety of voltage waveforms, such as square waves, sawtooth waves, trapezoidal waves, rectangular waves, brief rectangular pulses, and sharp peaks.

In the sound reproduction circuits for radio, tubes operate within the limits for which they are designed; but in radar timing circuits, they are often violently overdriven, frequently operating at points which range from well in the grid current region to far beyond cutoff. Although all of these circuits are broadly classified as timing circuits, the specific function of any individual circuit might be timing, waveshaping, or wave generating.

The basic function of the radar timer is to synchronize the sweep voltage or current for the indicator with the transmitter pulse. The specific function is to produce the trigger pulse that starts the transmitter, the sweep circuits, rangemark generators, blanking circuits, and gating circuits. (See fig. 9-1.)

BASIC REQUIREMENTS

The basic timing circuit should meet three basic requirements:

1. It must be free running (astable)–since the timer is the heart of the radar, it must establish the zero time reference and the PRF.
2. It must be stable in frequency (PRF)–the PRF, or its reciprocal, the PRT, must not change between pulses for accurate ranging.
3. The frequency must be variable in steps for the radar to operate on different ranges.

There are three basic circuits that can meet the above mentioned requirements. They are the sine-wave oscillator, single-swing blocking oscillator, and the master trigger multivibrator.

The multivibrator timer is discussed because of its greater usage due to its better frequency stability.

MULTIVIBRATOR TIMER

Some of the information dealing with multivibrators, as presented in this chapter, may seem repetitious of Basic Electronics, NavPers 10087-C, Vol. 2. Since this chapter is written for Aviation Electronics Technicians First and Chief, the treatment of multivibrators must be more thorough. The preliminary data is given as an aid in introducing more complicated aspects of the subject.

The multivibrator (square wave generator) is a form of relaxation oscillator. There are several different types in use, depending on the

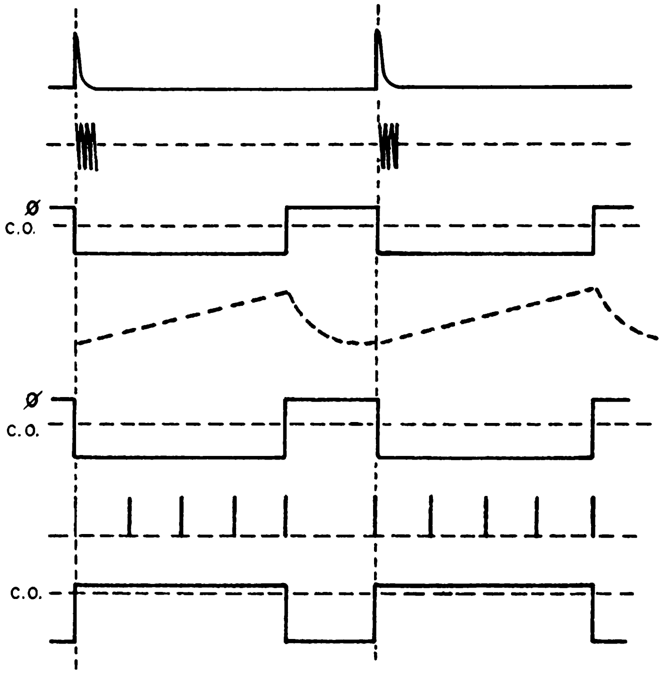

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Figure 9-1.–Synchrogram of timer pulses.

function they are required to perform. They are used for time sharing, gating, counting, and timing bases. Some of these circuits produce a specified wave shape repeatedly as long as power is supplied. Others produce one wave when pulsed, and remain inactive until another pulse is applied to the circuit; then they produce another wave. The output wave shape is the same regardless of the waveshape or amplitude of the initiating or TRIGGER pulse. Those which run continuously with only power applied are called free-running multivibrators. Those which produce one complete cycle of operation for each synchronizing pulse are called ONE-SHOT, ONE-CYCLE, or MONOSTABLE. Those which produce only a half cycle of operation for each synchronizing pulse are called BISTABLE, FLIP-FLOP, or SCALE-OF-TWO circuits. The frequency of free-running multivibrators, as with other types of oscillators, is influenced by all voltages and component sizes associated with the circuits. Therefore, although such circuits have only fair frequency stability when free running, adequate stability is readily achieved from a reliable a-c synchronizing voltage.

The square waveshape produced can be differentiated to produce accurately spaced peaked waveshapes. The duration and amplitude of any of the waveshapes are readily varied. Time delayed pulses can be produced by triggering a multivibrator with a peaked wave, letting it go through a cycle, and obtaining a new peaked wave somewhat later from the square wave produced.

Plate Coupled Multivibrator

The plate coupled multivibrator is the simplest of the multivibrators. The basic operating principles of this circuit are discussed in Basic Electronics. The following paragraphs are devoted to a quantitative analysis of the circuit and a discussion of methods for improving circuit action.

QUANTITATIVE ANALYSIS.–It is fairly easy to calculate the frequency and approximate voltage throughout a given circuit of this type.

Consider, for example, the circuit shown in figure 9-2 (A). A plate voltage of 300 volts is applied to a 6SN7 dual triode with the circuit components shown. The plate voltage of V1 varies between the value corresponding to zero grid voltage and the value corresponding to zero plate current. You can determine these values from a 20-K loadline on the 6SN7 characteristic curves. The loadline crosses the zero grid voltage line at a plate voltage of 97 volts. At zero plate current, the plate voltage is 300 volts. From this information you can construct the plate voltage waveshape.

All this plate voltage change occurs across the grid resistor of V2 at the first instant. The resistor voltage is the grid voltage for V2; so the grid will swing negative by the same amount that the plate voltage drops. The plate voltage drops from 300 to 97, or 203 volts. The grid is at zero when the plate voltage drop occurs, so the

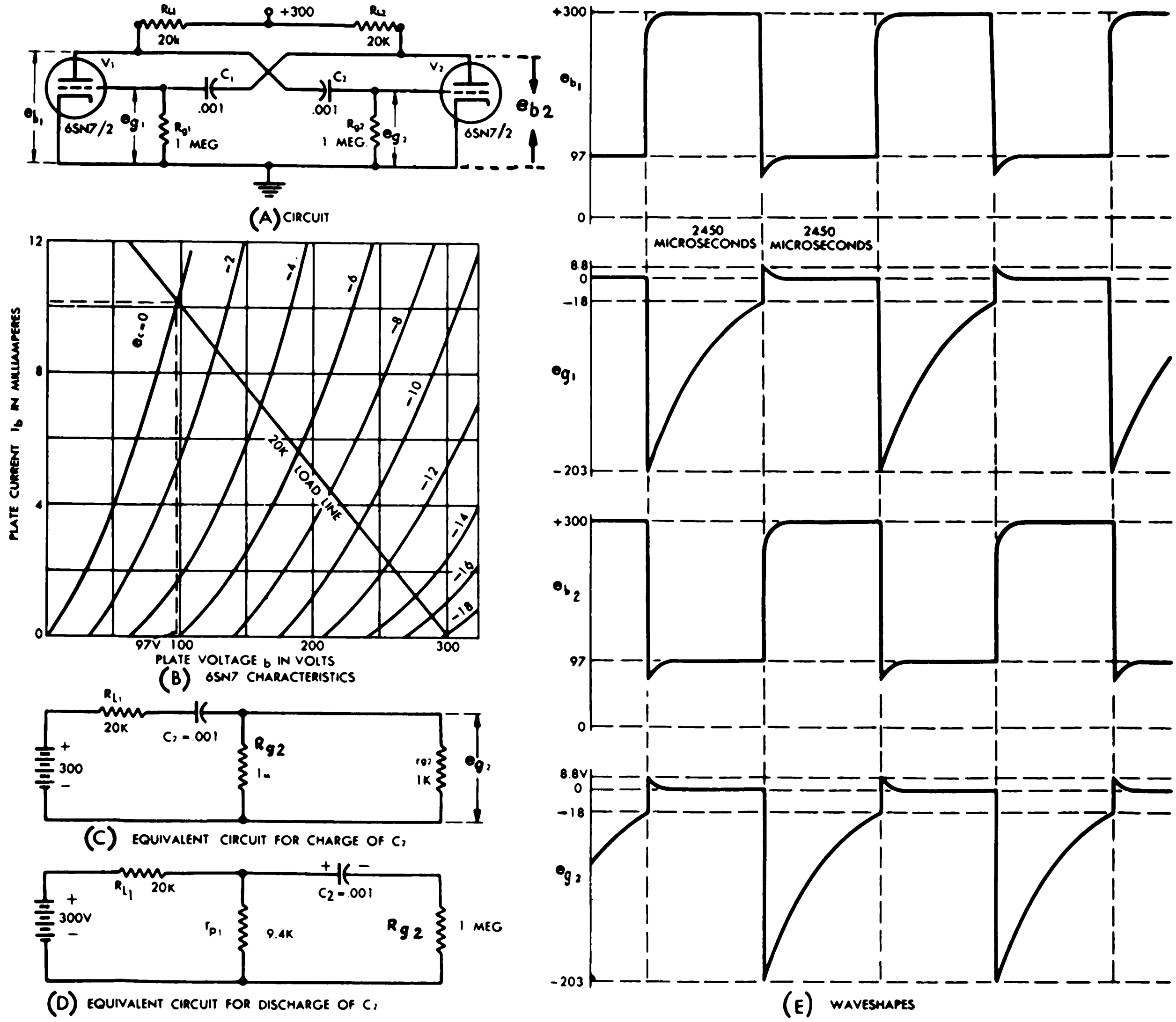

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Figure 9-2.—Quantitative analysis of plate coupled multivibrator.

grid immediately goes 203 volts negative. The equivalent circuit during the discharge is shown in (D) of figure 9-2. The voltage across r_{p1} (the tube's plate resistance) is 97 volts. The plate resistance r_{p1} is found by using the plate current and voltage when the grid voltage of V1 is zero.

$$r_{p1} - e_b/i_b - 97/10.3 \text{ ma} = \text{about } 9.4 \text{ K ohms}$$

In parallel with this (through the battery) is the 20-K plate load resistor. This parallel combination will have a resistance of about 6 K and will be in series with the 1-megohm resistor. For simplicity this 6-K resistance can be disregarded. This will introduce an error of less than one percent. The discharge time constant without the 6-K resistance will be 0.001 μf x 1 megohm = 1,000 microseconds.

Capacitor C2 discharges exponentially until the grid voltage of V2 is just above cutoff. Cutoff voltage for this tube with 300 volts applied is minus 18 volts as read from the characteristic curves. The cutoff period is terminated when the voltage drops to 18/203 or 0.089 of its initial value. The grid voltage is down to this value in 2.45 time constants, as calculated from the capacitor discharge curve on the universal time constant chart in Basic Electricity. Since the discharge time constant is 1,000 microseconds, the cutoff time equals 2.45 time constants multiplied by 1,000 microseconds or 2,450 microseconds.

The cutoff time for tube V2 will be 2,450 microseconds. Since the resistor and capacitor values are exactly the same, tube V1 will be cut off for 2,450 microseconds during the other half cycle of operation. The grid and plate voltage values and curves will also be identical. If a difference exists in the circuit of each tube, separate calculations must be carried out for each half cycle. In this case, 2,450 + 2,450 = 4,900 microseconds. The frequency at which square waves are produced is the reciprocal of the duration.

$$F = \frac{1}{4{,}900 \times 10^{-6}} = 204 \text{ Hz}$$

The duration and amplitude of the positive peak on the grid waveform can be readily calculated from the equivalent circuit shown in (C) of figure 9-2. The positive peak occurs as the capacitor is charged to a higher plate voltage. The capacitor charges through the resistance that consists of the plate load resistor for V1 and the grid to cathode resistance of V2. This is a total of 21K. The 1-megohm resistor carries only 0.1 percent of the charging current and is therefore safely disregarded. With the 0.001-μf capacitor the time constant is 0.001 x 10^{-6} x 2.1 x 10^4 or 21 microseconds. If the charge requires 5 time constants, the positive peak will disappear after a hundred microseconds.

The amplitude of the peak can be determined by using Ohm's law. The total voltage rise at the plate of V1 is 203 volts. This raises the grid voltage from cutoff (minus 18 volts) to some positive value. Since the first 18 volts of plate voltage rise changes the grid voltage to zero, the remaining rise above zero is 203 - 18, or 185 volts. This causes grid current to flow and the voltage to divide across the series combination of the grid to cathode resistance and the plate load resistance. As the grid to cathode resistance equals 1,000 ohms, and the plate load resistance equals 20,000 ohms, 1/21 of the 185 volts, or 8.8 volts, appears across the grid to cathode resistance. Thus the positive peaks at the grid will be 8.8 volts above zero.

Because the plate voltage cannot rise faster than the capacitor can charge, the plate voltage rise is exponential over a period of 100 microseconds. This rounds off the leading edge of the plate waveshape. The positive grid at the other tube causes a dip in plate voltage at that tube. The output from this circuit is normally taken from either plate although the grid voltage is sometimes useful.

In the chart (fig. 9-3) showing the effects of varying the sizes of the component parts of this circuit, the essential data is given, but the detailed and less important effects are omitted because of a lack of space. The effects of changing $R_{L}2$, $R_{g}2$, C2, and V2 are not listed since these effects are similar to those that result from changing R_{L1}, R_{g1}, C1 and V1 respectively–except that each effect occurs with the other half cycle of operation.

A detailed discussion of various transistorized multivibrator circuits is presented in chapter 3 of Basic Electronics, Vol. 2.

Improving Circuit Action

There are a number of slight changes that can be made in the basic plate coupled

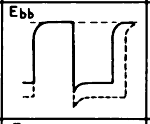
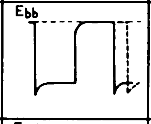
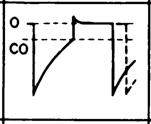
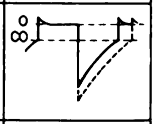
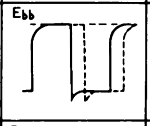
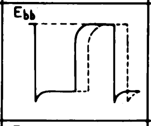
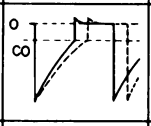
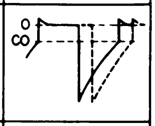
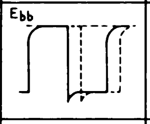
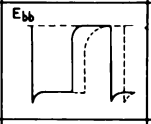
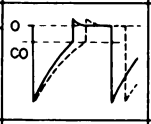
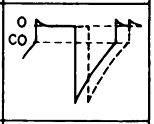
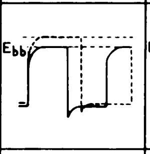
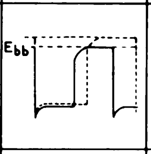
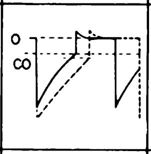
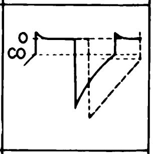
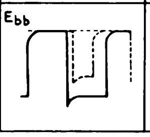
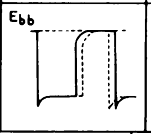
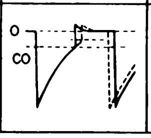
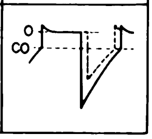
CHANGE	FREQUENCY	AMPLITUDE OF e_{b1}	DURATION e_{b1} AT E_{bb}	AMPLITUDE e_{b2}	DURATION e_{b2} AT E_b	WAVESHAPE CHANGE ——— BEFORE CHANGE -------AFTER INCREASE			
						e_{b1}	e_{b2}	e_{g1}	e_{g2}
$R_{l,1}$ INCREASED	DECREASED. V_2 CUTOFF LONGER.	INCREASED. e_{b1} IS LOWER DURING ZERO GRID VOLTAGE TIMES	UNCHANGED	UNCHANGED	LONGER. GRID IS MORE NEGATIVE AT START OF C.O TIME				
R_{g1} INCREASED	LOWER. V_1 CUTOFF LONGER	UNCHANGED	LONGER. TUBE IS CUT OFF LONGER	UNCHANGED	UNCHANGED				
C_1 INCREASED	LOWER. V_1 CUTOFF LONGER	UNCHANGED	LONGER	UNCHANGED	UNCHANGED				
E_{bb} INCREASED	LOWER. BOTH GRIDS DRIVEN BELOW CUTOFF. CUT OFF VALUE LOWERS SLIGHTLY.	INCREASED. E_b GOES UP. e_{b1} VALUE FOR ZERO GRID VOLTAGE GOES UP SLIGHTLY.	INCREASED. V_1 IS CUTOFF LONGER.	INCREASED. E_b GOES UP. e_{b2} VALUE FOR ZERO GRID VOLTAGE GOES UP SLIGHTLY.	INCREASED. V_2 CUTOFF LONGER.				
V_1 REPLACED WITH TUBE OF HIGHER Mu.	HIGHER	DECREASED. HIGH r_p OF V_1 CAUSED e_{bb} FOR ZERO GRID VOLTAGE TO BE HIGHER.	SLIGHTLY LONGER. CUTOFF FOR V_1 IS LOWER.	UNCHANGED	DECREASED SINCE GRID OF V_2 IS NOT DRIVEN VERY FAR NEGATIVE.				

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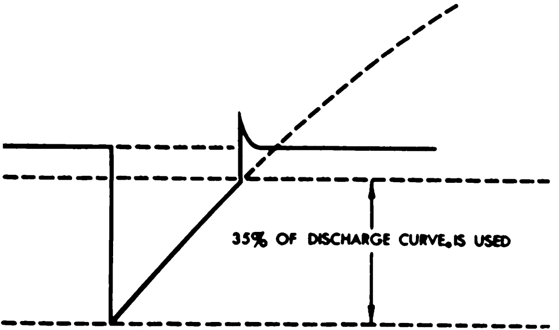
Figure 9-3.—Effects of varying elements in multivibrator.

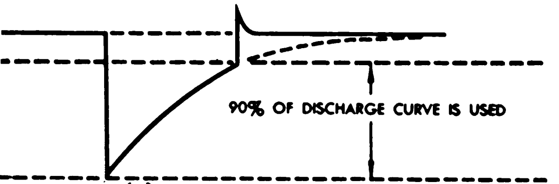
multivibrator circuit to improve its stability and output waveshape. One is to return the grids to a positive voltage, and another is to use series limiting resistors.

RETURNING THE GRIDS TO A POSITIVE VOLTAGE.—Returning the grids to a positive voltage improves the stability of a plate coupled multivibrator. In this arrangement, the grid-leak resistors are often connected to the source of plate voltage; in other words, the grids are returned to B plus. Under this condition the grid current flow causes the B-plus potential to exist mostly across the resistor while the grid to cathode voltage remains within a fraction of a volt or zero. When the plate voltage of the other tube drops, the capacitor discharges as usual, with a current that is high enough to drive the grid negative by the amount of the plate voltage drop. Due to this condition the exponential discharge of the capacitor appears as though the capacitor were charged to the plate voltage drop plus the plate voltage supply. The net result is that the curve shown in figure 9-4 (A), resulting from the negative peak value to cutoff, is much more linear due to the fact that a smaller percentage of the discharge curve is used.

Returning the grids to a positive voltage produces an advantage in that the discharge curve strikes cutoff at a more nearly vertical angle. This means that if variations of voltage or temperature in the circuit affect the relation of the waveshape to the cutoff value only a small change of time will occur. In contrast, study the grid voltage curve in (B) of figure 9-4 where the grid resistor is grounded. The discharge curve is almost parallel at the cutoff value. In this case a small variation of the cutoff value will cause a large time change. In conclusion, then, returning the grids to B plus decreases



(A) e_{g1} WITH GRID RETURNED TO +300V



(B) e_{g1} WITH GRID RETURNED TO GROUND

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gure 9-4.–Improving the basic circuit.

HANGE in duration of pulses and the free-ing frequency for a given change in circuit tants.

ou can increase your understanding of the t of returning the grid to B plus by making titative analyses and studying equivalent iits. In figure 9-5 (C), notice the equivalent ging circuit of C1 during the time that V1 nducting. In (B), the parts of the circuit ved during the charge of C1 are shown. e the grid to cathode resistance is very l, compared to the grid-leak resistor, it be represented as a direct connection, ucing the equivalent circuit in (C). Here s relatively small; as a result the capacitor be fully charged before tube V2 starts to uct. Thus, while V2 is cut off, capacitor as a charge of 300 volts.

he discharge circuit for C1 is shown in V2 is brought into conduction at this time, ing a 203-volt drop across the load resistor A closed circuit is formed as shown in (E). voltage across the load resistor may be idered as a source of voltage or battery n is of a polarity to aid the capacitor in causing current flow. The total voltage across the resistor R3 becomes the capacitor charge plus the load resistor voltage (300 + 203 = 503 volts). The grid end of resistor R3 is 503 volts negative with respect to the end connected to 300 volts. As a result, the grid of V1 is 203 volts negative with respect to its cathode.

Since the direction of capacitor current is reversed, the plate voltage source will aid the discharged of the capacitor. When a source is connected to a charge capacitor with a polarity that discharges it, the capacitor will completely discharge and recharge to the new voltage all in one long exponential curve. In this case, the curve will have the same amplitude as it would if charged from zero to 503 volts. The resulting slope is as shown in figure 9-4 (A). Of course, the slope due to the more rapid discharge will go through zero earlier if the same RC is used. Therefore a longer RC must be used when grid resistors are returned to a positive voltage than is used when the resistors are returned to ground, for the same duration of output pulse.

SERIES LIMITING RESISTORS.–The use of series limiting resistors in the grid circuits of this multivibrator increases the squareness of the waveshapes. In the circuit shown in figure 9-6, these resistors are R5 and R6. The first half cycle of the plate and grid waveshapes shown is without the grid limiting resistors in the circuit, and the second half cycle is with R5 and R6 in the circuit. Note that the grid does not go positive when resistors are provided. When the other plate becomes more positive most of the voltage change occurs across the grid limiting resistor while only a small fraction of a volt exists between the grid and cathode, provided that the grid limiting resistor is of the order of 500K or more. The plate that is going positive cannot normally rise in voltage any quicker than the coupling capacitor can charge. Therefore in the normal circuit, the plate waveshape resembles the coupling capacitor charging curve. When grid limiting resistors are inserted, each limiting resistor is in series with the low grid to cathode resistance, and with the grid-leak resistor, forming a high resistance circuit for the capacitor to charge through. The circuit is like the trapezoidal sweep generator in that a "jump" voltage will occur across the limiting and grid-leak resistors. The exponential rise will start from there. In the waveshape of this illustration, the jump is about 90 percent of the total

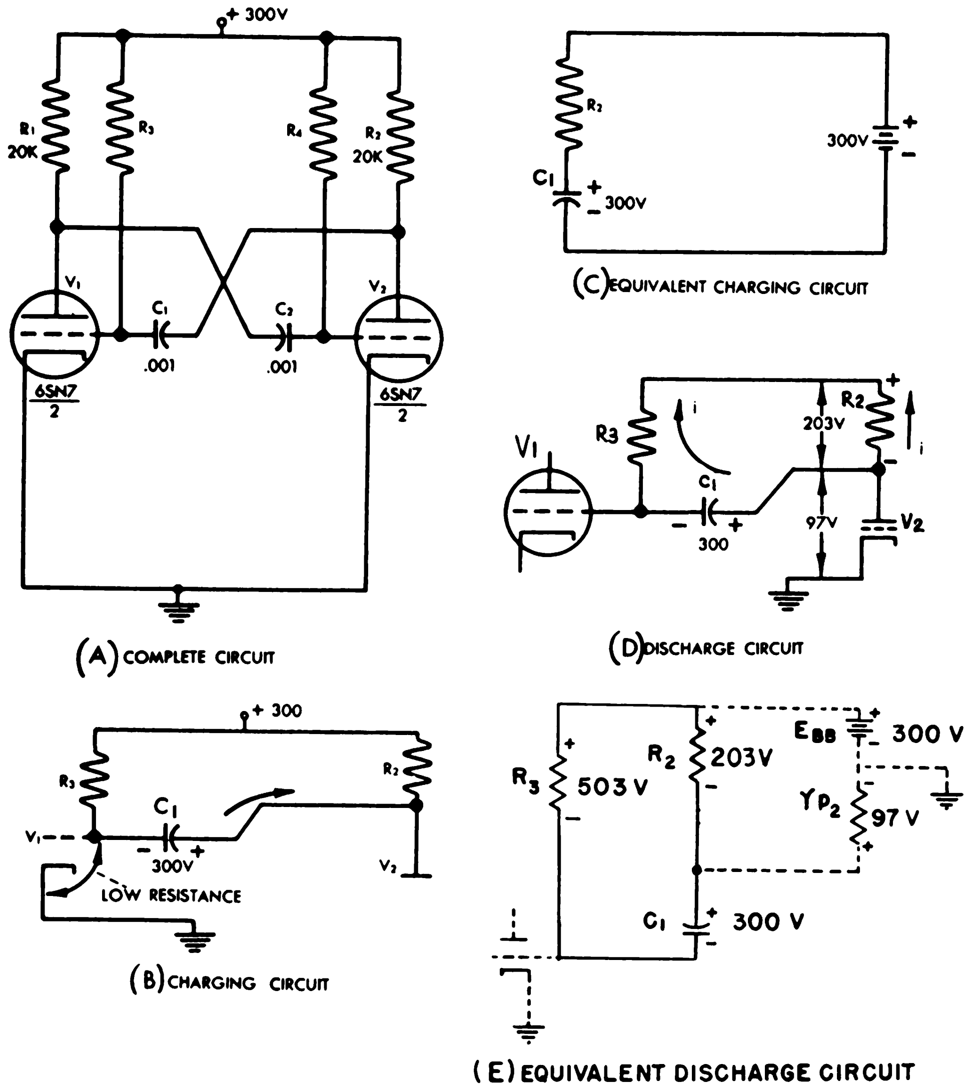

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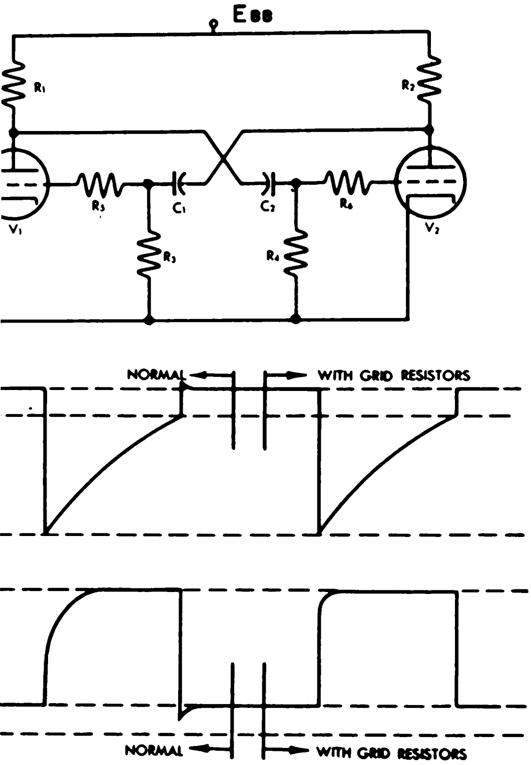
Figure 9-5.—Effect of returning grid to B plus.

amplitude, with only slight rounding of the leading edge of the pulse.

RADAR SWEEP CIRCUITS

The range sweep in a radar set is of paramount importance for the correct presentation of target information. To accomplish this, a sawtooth voltage or current of proper amplitude and slope must be supplied to the indicator's deflection system. This discussion will include a typical range sweep circuit used for generating a linear sawtooth of the proper amplitude and time duration. The same circuit is used to generate the sweep for more than one range, and yet maintain the same physical sweep length on the scope. Since the basic circuits involved in the sweep generator are discussed in Basic Electronics, Vol. 2, only its actual operating condition is explained in detail in this chapter.



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ure 9-6.–Using series limiting resistors.

EP GATE CIRCUIT

'he sweep gate circuit consists of a one-shot ivibrator, V6 and V8 (fig. 9-7), a negative clamper. V7, and two sweep gate amplifiers and V7. (NOTE: V26 and V27 are dis- ed later in the chapter.) It should be noted V8 is cut off in static condition by the volt- divider network in its grid circuit and that s conducting. The circuit is triggered by gative pulse which is applied to the grid of It should be recalled from the discussion he timer block diagram (chapter 8) that the p gate circuit is triggered by a negative e from either the master trigger output on ial operation, or the variable delay circuit me delay operation.

'he negative input trigger pulse drives V6 rd cutoff, causing a rise in its plate voltage a drop in its cathode voltage. This plate ge rise is coupled to the grid of V8, driving V8 into conduction. The resulting drop in plate voltage is coupled back to the grid of V6 as in any one-shot multivibrator. However, the negative grid clamper does not permit the grid of V6 to be driven below an approximate negative 23 volts.

The action of V7 and the sweep shutoff circuit (fig. 9-8) controls the duration of the output pulses from the sweep gate circuit. (NOTE: The output from the sweep gate determines range sweep time which is discussed later in this chapter.)

The outputs of the sweep gate circuit are as follows:

1. A negative square wave (generated by conduction of V8 through R29 and capacitively coupled to the grid of V6) from the grid of V6 which is fed to the grid of sweep gate amplifier V27.
2. A negative square wave from the cathode of V6 which is used to trigger the compensating gate circuit.
3. A positive square wave from the cathode of V8 which is used as a gating voltage. The relationship of the output waveforms to the master timing pulse is shown by waveforms (1), (2), and (3) of the figure 9-9.

The sweep gate amplifier V27 and sweep gate output V26 circuits are discussed later in this chapter with the intensity gate circuit.

SWEEP CLAMP, SHUTOFF, CHARGING CLAMP, AND BOOTSTRAP AMPLIFIER

Before considering the overall operation of the circuit illustrated in figure 9-8, the functions it performs are discussed. The circuit may be divided into three stages with each stage performing a separate function.

The first stage consists of the RC network composed of C18 to C21, R37, R38, R39, and the two diodes V10A and V10B. The RC network is used to generate a sawtooth waveform for use as a range sweep voltage. V10A and V10B function to clamp the upper plates of the sweep capacitors (C18 through C21) at near ground and provide a means of eliminating the clamping action during sweep time.

The stage V9 controls the amplitude of the sawtooth voltage waveform. It also generates a pulse which cuts off the sweep gate output voltage when the sawtooth voltage reaches the desired amplitude.

It should be remembered that at any instant the charge on a capacitor depends on the RC

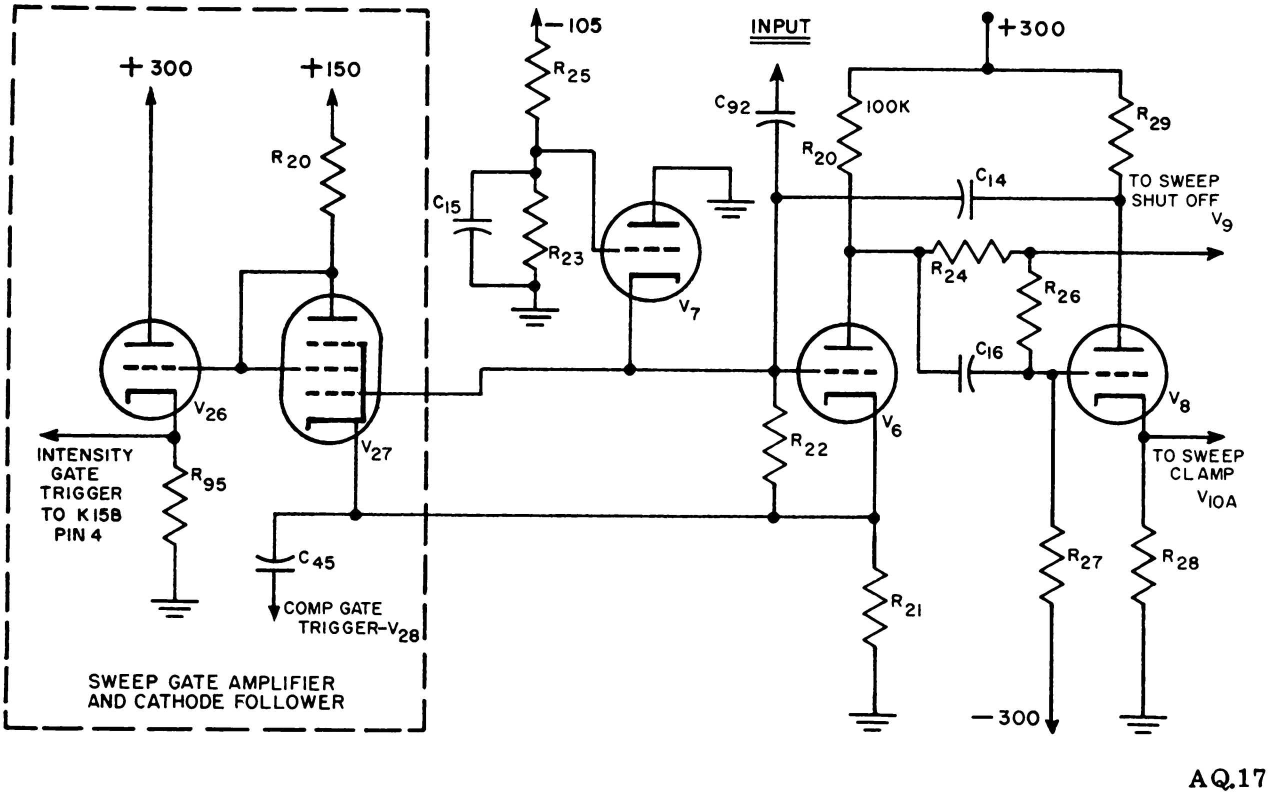

Figure 9-7.—Sweep gate circuit.

time of the network and the applied voltage. For the fixed ranges (all ranges except 5-60 miles), range is controlled by switching in various size capacitors and the applied voltage is held at a positive 150 volts. In the variable range (5-60) mode of operation, the applied voltage is varied by the variable range control R606.

Referring to figures 9-7 and 9-8 note that without an input signal, current (electron flow) will flow from ground up through R28 to the cathode of V10A, from cathode to plate of V10A, through R37 and R39 to cathode of V10B, from cathode to plate of V10B, and to pin 8 of relay K6. Pin 8 of K6 is connected to a positive 150 volts through pin 7 when the equipment is operating on a fixed range. When operating on a variable range, pin 8 is connected to the variable range control R606 which forms a voltage divider network between ground and a positive 150 volts.

The path from K6 through R34 to the top of R35 has negligible effect because of its high resistance. The static current maintains the plate of V10A at a relatively low potential which also determines the static voltage across capacitors C18 thru C21. (The relative size of R28 to R37 plus R39 clamps the plate of V10A slightly above ground.) The sweep cutoff tube V9 is biased beyond cutoff by a positive potential applied to the voltage divider network in its cathode circuit. The cathode potential of V9 is important since it determines sweep amplitude which indirectly controls sweep time.

Now consider the operation of the circuit when a signal is applied. (For the following discussion refer to waveforms illustrated in figure 9-9.) A positive square wave taken from the cathode of V8 is applied to the cathode of V10A. It should be remembered that this square wave is generated by the sweep gate

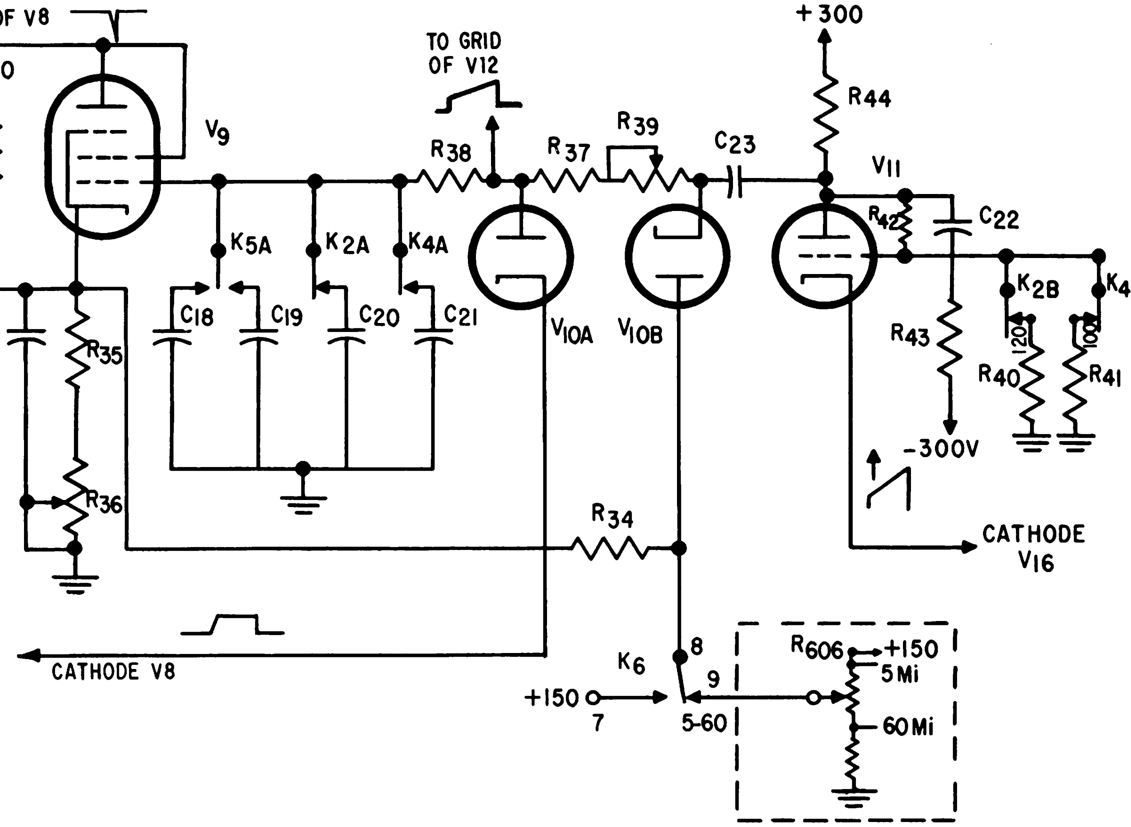

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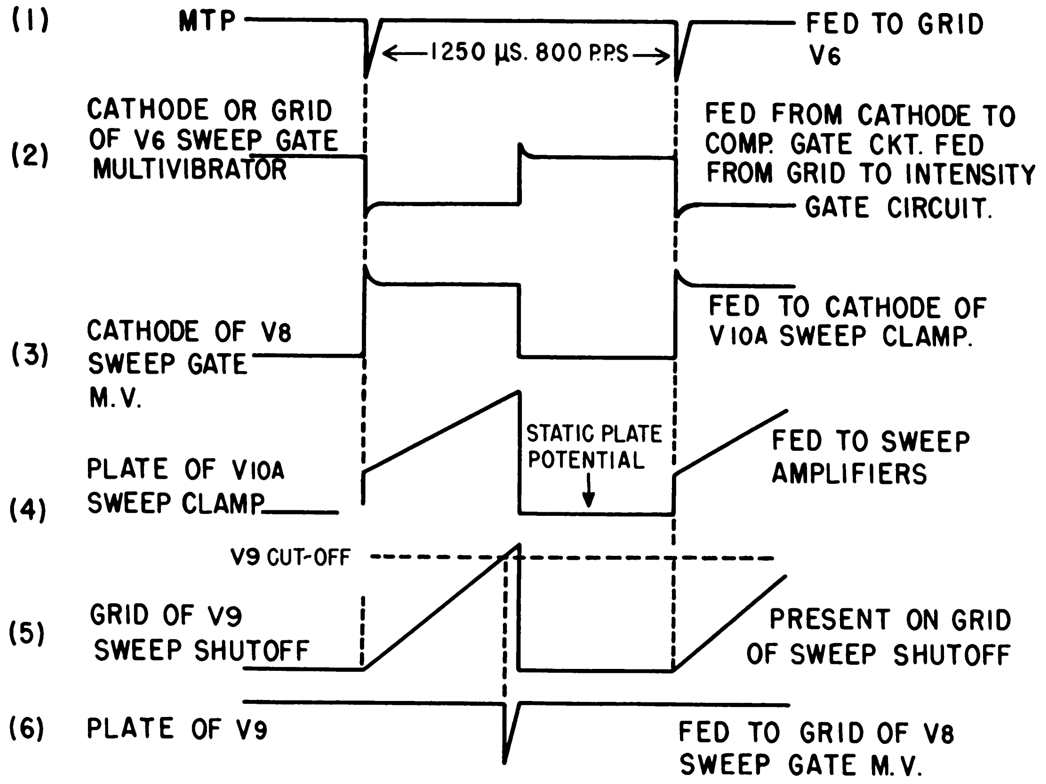
Figure 9-8.–Sweep clamp, shutoff, charging clamp, and bootstrap amplifier.

rator. With the cathode of V10A now
sitive than its plate, V10A is effectively
from the circuit. The sweep charging
rs (C18 thru C21) may now charge at
ate as determined by the RC network
sed. As the sweep capacitors charge
150 volts (assume fixed range opera-
e grid of V9 will also rise at the same
hen the grid voltage rises sufficiently
ome its cathode bias, V9 will conduct,
g a negative-going pulse of sufficient
e to cut off V8. Since the conduction
rovided the voltage source which cut off
nping circuit (V10A), the circuit will
rn to its static condition.

time required for V9 to conduct was
ned by its static cathode potential and
etwork being used to generate the saw-
ltage waveform (assuming a constant
mplitude). Therefore sweep time is controlled by varying the values of resistance and capacitance in the charging circuit on all fixed ranges.

The relationship of the MTP to the waveforms of the range sweep generating circuits is shown in figure 9-9. Waveform (3) is the positive square wave which disables the clamper V10A. It should be noted that waveforms (4) is a sawtooth superimposed on a low amplitude square wave. The square wave portion, called a jump voltage, is developed across R38 when V10A is cut off. Waveform (5) should be studied noting that when the sawtooth voltage reaches cutoff, waveforms (2), (3), and (4) are also terminated.

The output of the sweep charging circuit, a positive sawtooth on a pedestal, taken from the plate of V10A is directly coupled to the grid of the sweep amplifier V12. (NOTE: The operation of V11 has been omitted purposely at this


(1)
MTP
1250 µS. 800 P.P.S
FED TO GRID V6
(2)
CATHODE OR GRID OF V6 SWEEP GATE MULTIVIBRATOR
FED FROM CATHODE TO COMP. GATE CKT. FED FROM GRID TO INTENSITY GATE CIRCUIT.
(3)
CATHODE OF V8 SWEEP GATE M.V.
FED TO CATHODE OF V10A SWEEP CLAMP.
(4)
PLATE OF V10A SWEEP CLAMP
STATIC PLATE POTENTIAL
FED TO SWEEP AMPLIFIERS
V9 CUT-OFF
(5)
GRID OF V9 SWEEP SHUTOFF
PRESENT ON GRID OF SWEEP SHUTOFF
(6)
PLATE OF V9
FED TO GRID OF V8 SWEEP GATE M.V.

AQ. 19

Figure 9-9.—Waveforms of the sweep generating circuits.

time; however, it is discussed later in this chapter.) This output waveform is shown as waveform (1) of figure 9-10.

Sweep adjustments are provided to allow the technician a means of compensating for any slight variations in circuit parts. R36, located in the cathode V9, is a screwdriver adjustment for setting the sweep amplitude. R39 is a similar adjustment, but it permits a fine adjustment of the sweep slope or sweep time.

SWEEP AMPLIFIER CIRCUITS

You should now be familiar with how the sawtooth sweep is generated and how it is used as a time base for the measurement of range. However, this sawtooth must be amplified before it is applied to the deflection system of the indicator. The sweep amplifier circuits also provide a means of feedback to improve the linearity of the sweep voltage. The feedback voltage is taken from the sweep driver stage and fed to the bootstrap amplifier V11.

The basic circuits utilized in the sweep amplifier circuits are discussed in detail in Basic Electronics, NavPers 10087-C, Vol. 2. Therefore, only the operation of the sweep amplifier and its waveforms are discussed. Figure 9-10 is an illustration of the waveforms throughout the sweep amplifying chain. Reference to waveforms illustrated are by number as shown. Figure 9-11 is the schematic of the sweep amplifying circuits and should be referred to for the following analysis.

As stated previously, the positive sawtooth on a pedestal is coupled directly from the plate of the sweep clamper V10A to the grid of the first sweep amplifier V12 (waveform (1), fig. 9-10). Note that the cathode of V12 is returned to ground through the sweep driver's cathode resistor. This provides degenerative feedback which improves the linearity of the amplifying

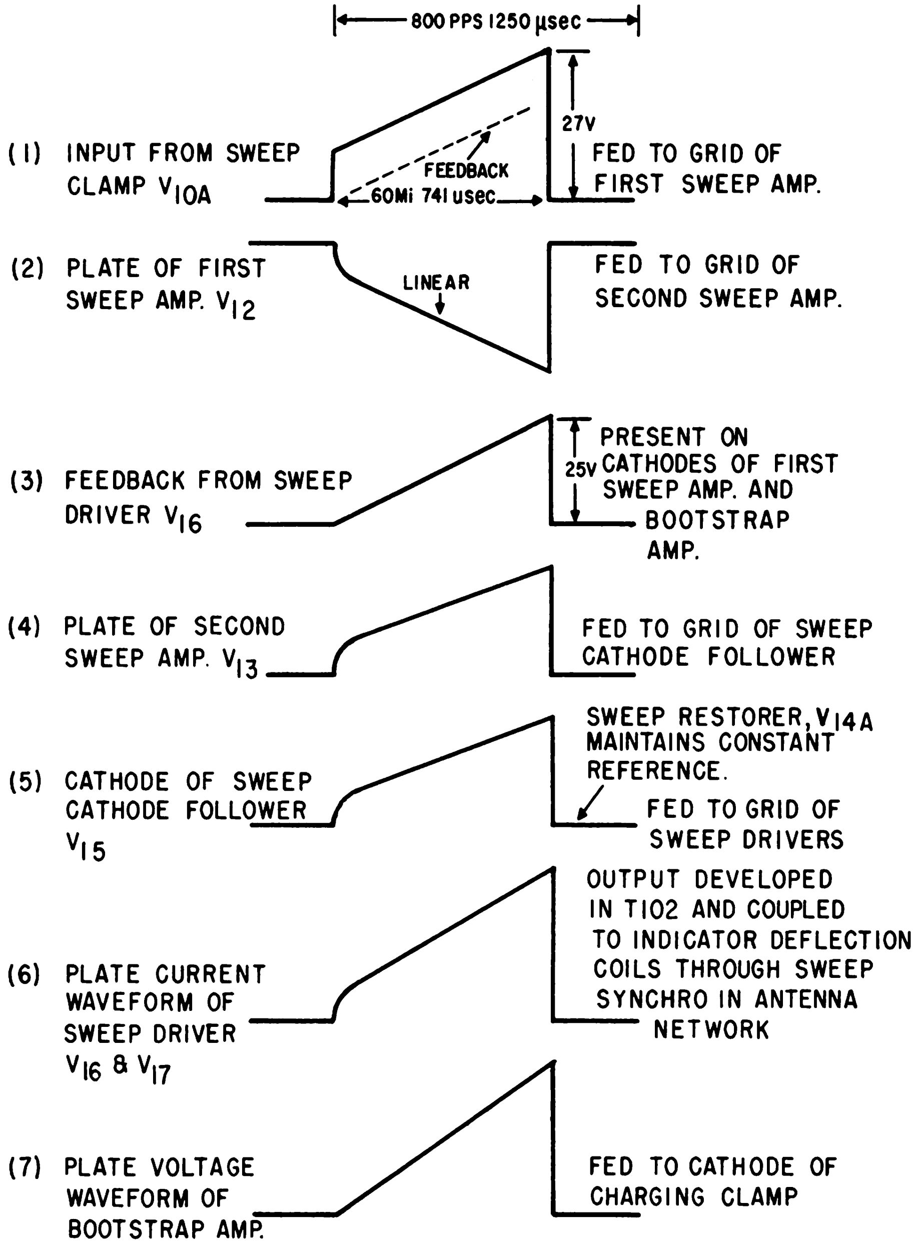
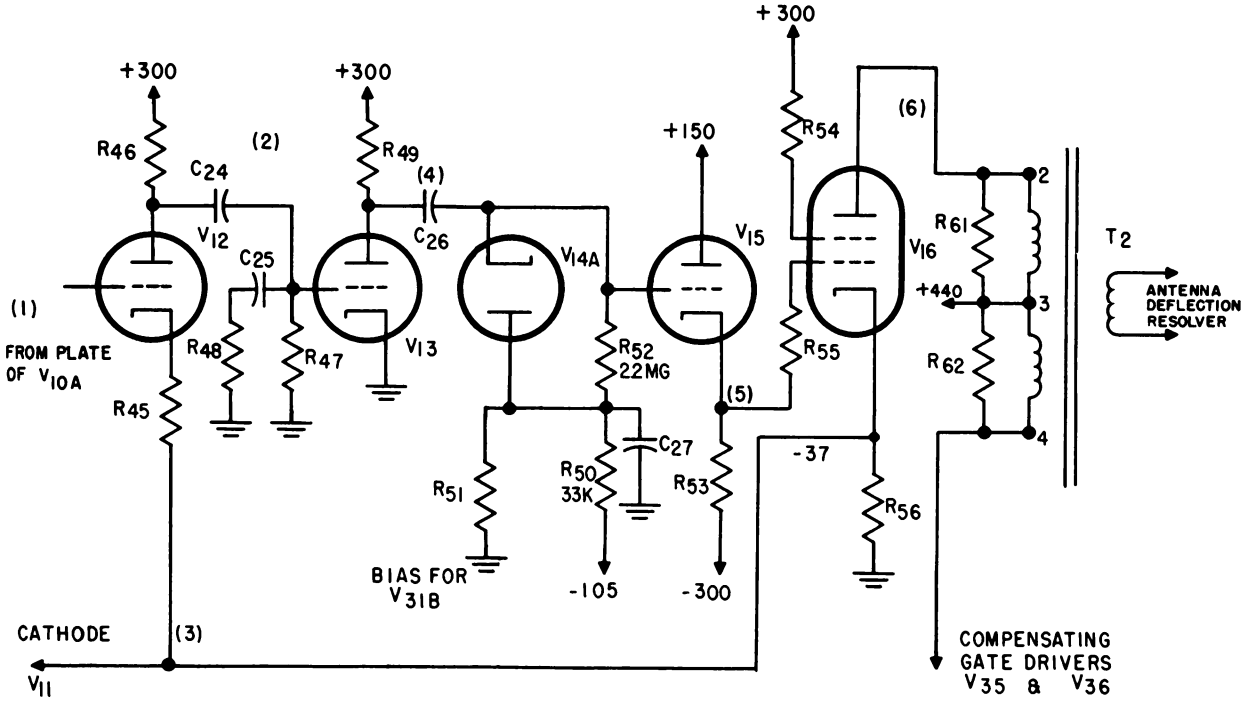

800 PPS 1250 μsec
(1) INPUT FROM SWEEP CLAMP V10A
FEEDBACK
60Mi 741 usec
27V
FED TO GRID OF FIRST SWEEP AMP.
(2) PLATE OF FIRST SWEEP AMP. V12
LINEAR
FED TO GRID OF SECOND SWEEP AMP.
(3) FEEDBACK FROM SWEEP DRIVER V16
25V
PRESENT ON CATHODES OF FIRST SWEEP AMP. AND BOOTSTRAP AMP.
(4) PLATE OF SECOND SWEEP AMP. V13
FED TO GRID OF SWEEP CATHODE FOLLOWER
(5) CATHODE OF SWEEP CATHODE FOLLOWER V15
SWEEP RESTORER, V14A MAINTAINS CONSTANT REFERENCE.
FED TO GRID OF SWEEP DRIVERS
(6) PLATE CURRENT WAVEFORM OF SWEEP DRIVER V16 & V17
OUTPUT DEVELOPED IN T102 AND COUPLED TO INDICATOR DEFLECTION COILS THROUGH SWEEP SYNCHRO IN ANTENNA NETWORK
(7) PLATE VOLTAGE WAVEFORM OF BOOTSTRAP AMP.
FED TO CATHODE OF CHARGING CLAMP

Figure 9-10.—Waveforms of the sweep amplifying chain. AQ.20

circuits. This should not be confused with the feedback loop through the bootstrap amplifier to the sweep generator. Feedback within the sweep amplifiers aids in eliminating distortion that may be generated within the sweep amplifier circuits. The feedback voltage is illustrated by waveform (3). The relative amplitudes of the two signals applied to V12 should be noted. Thus, the output of V12, because of the feedback voltage, has been greatly reduced.

A linear negative sawtooth on a pedestal is coupled to the grid of the second sweep amplifier V13. The oscillation suppression circuit, consisting of C25 and R48 in the grid circuit of



AQ. 21

Figure 9-11.—Sweep amplifying circuits.

V13, acts as a low impedance path for high frequency oscillations. (NOTE: A sudden change in input voltage such as the trailing edge of waveform (1) may shock-excite an amplifier into oscillating.) The second sweep amplifier also amplifies and inverts the signal as shown by waveform (4). Its output, a positive sawtooth on a pedestal, is fed to the grid of the cathode follower V15.

The cathode follower is used to match the high impedance output of the second sweep amplifier to the low input impedance of the sweep driver. In static condition, V15 is biased negative by the voltage divider network in its grid circuit. However, with the plate of V15 connected to a positive 150 volts and its cathode connected through R53 to a negative 300 volts, it will conduct and bias V16 at approximately minus 40 volts. The diode V14A is used as a clamper to return the grid to its static potential following each sawtooth input.

The sweep driver receives the positive trapezoidal voltage (sawtooth on a pedestal) from the sweep cathode follower. As the slope of the waveform is reduced (longer ranges), the pedestal amplitude is also reduced.

The output transformer T2 is the plate load for the sweep driver. As shown in waveform (6), a linear positive sawtooth of current appears in its primary with each input. It is combined with a signal from the compensating gate driver which is discussed later in this chapter. Resistors R61 and R62 are in parallel with the primary of T2 and are used to dampen oscillations of the transformer. Degenerative feedback resulting from the unbypassed cathode resistor R56 also aids in reducing oscillations as well as providing a source of signal which is fed back to earlier stages. A sweep reference level signal is also fed from this point to the sweep compensating gate circuit.

Bootstrap Amplifier

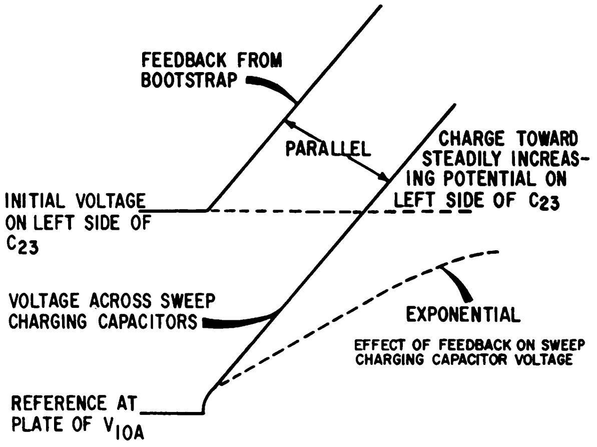
Now that the basic operation of the sweep circuits has been discussed, the action of the bootstrap amplifier will be explained. For the following discussion refer to figure 9-8.

The input to the bootstrap amplifier (applied to the cathode) is a linear positive sawtooth voltage from the cathode of the sweep driver. The amplitude of the input signal is proportional to the output current of the sweep driver. The output of the bootstrap amplifier is also a positive sawtooth voltage which is slightly greater in amplitude than its input signal. This output is coupled to the sweep generating circuit through C23.

In explaining the operation of the sweep generating circuit, it was stated that the charge path of the sweep capacitors was through V10B and relay K6 to the voltage source. This statement is not true when considering the operation of the bootstrap amplifier. Since coupling capacitor C23 plays an important part in the operation of the circuit, consider in detail its static condition. The left plate of C23 is connected to the cathode of V10B and will be at plus 150 volts on all but the 5-60 mile range. The right plate is connected to the plate of V11 which is at approximately plus 80 volts during static condition. The capacity of C23 is much greater than that of the capacitors used by the sweep generating circuit on any range. Therefore, should the charge on C23 be used as a source of voltage during the time the sweep is being generated, the sweep charging current would have negligible effect on the voltage across C23.

(NOTE: The use of a charged capacitor as a source of voltage for short periods of time has been employed in numerous cases in radar equipment.) Now consider the operation of the sweep generating and bootstrap amplifier circuits. When the pulse from the sweep gate multivibrator cuts off V10A, the sweep capacitors will begin to charge as stated in the previous explanation. However, as the sawtooth is being generated, it is also being fed back to the bootstrap amplifier. This causes the voltage of the right side of C23 to rise. This rise in voltage is coupled to the sweep generating circuit by C23 which causes V10B to be cut off. From this point on to the end of sweep time, the charge on C23 and sawtooth on the plate of V11 will be the source of charging potential for the sweep generating circuit.

The sawtooth on the plate of V11 is of the same amplitude as that appearing on the plate of V10A. This increase results in a constant effective charging potential during sweep time for maximum linearity. Figure 9-12 illustrates graphically the voltage relationship during sweep time.


FEEDBACK FROM BOOTSTRAP
PARALLEL
CHARGE TOWARD STEADILY INCREASING POTENTIAL ON LEFT SIDE OF C_{23}
INITIAL VOLTAGE ON LEFT SIDE OF C_{23}
VOLTAGE ACROSS SWEEP CHARGING CAPACITORS
EXPONENTIAL
EFFECT OF FEEDBACK ON SWEEP CHARGING CAPACITOR VOLTAGE
REFERENCE AT PLATE OF V_{10A}

AQ. 22

Figure 9-12.—Effect of feedback on sweep charging capacitor voltage.

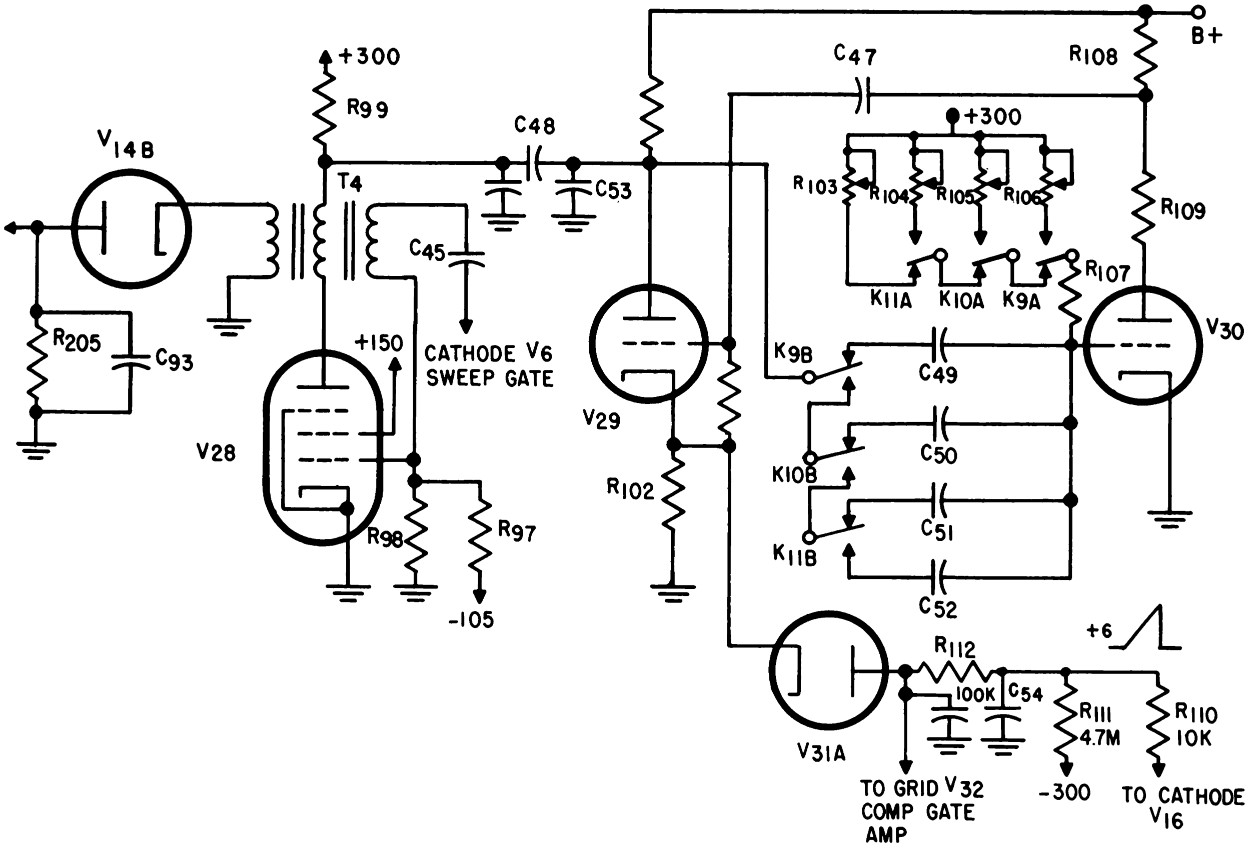
At the termination of sweep time, V10A and V10B conduct, resetting or clamping the potential of the capacitors in the circuit.

COMPENSATING GATE GENERATING CIRCUITS

As stated previously, the purpose of the compensating gate circuit is to generate a gating voltage that will cause the indicator's electron beam to be reset at the end of each range sweep, thus insuring that each trace on the indicator will start at the same point. The compensating gate circuit consists of a trigger generator, a multivibrator, a gate clamp, an amplifier, and a driver. It also utilizes two other diode clamp circuits to aid in maintaining proper reference potentials.

Compensating Gate Trigger

The compensating gate trigger V28 (fig. 9-13) is a single-swing blocking oscillator. It is biased beyond cutoff by the voltage divider network consisting of R97 and R98 in its grid circuit. It receives as its input a square wave from the sweep gate circuit. (NOTE: The relationship of this square wave to sweep time is important and is illustrated by waveforms (1) and (2) of figure 9-4.) However, the square wave is differentiated



AQ. 23

Figure 9-13.—Compensating gate circuit, part 1.

by C45, R97, and R98. The waveform as it appears at the grid of V28 is shown by waveform (3). The negative spike does not affect the operation of the circuit since the stage is cut off when it arrives. However, the positive spike drives the grid above cutoff which starts the oscillator to operating.

Once the grid is driven above cutoff, the oscillator operates as any single-swing blocking oscillator. The circuit has two outputs—(1) a negative spike taken from the remaining transformer secondary winding which is fed to the range marker circuit, and (2) a negative spike developed by the surge of plate current through the plate load resistor. The latter output is used to synchronize the compensating gate multivibrator V29 and V30.

Compensating Gate Multivibrator

This multivibrator is used to generate a positive square wave for gating the compensating gate clamp circuit. When the trigger pulse from the trigger generator arrives, V30 is conducting and V29 is cut off. The negative trigger pulse is coupled from the plate of V29 through one of the grid capacitors to the grid of V30. The pulse cuts off V30 and its rise in plate voltage is coupled back to the grid of V29, driving it to saturation. The time V30 remains cut off depends on the values of resistance and capacitance in the grid circuit. Relays K9, K10, and K11 are used to control the RC time in the grid circuit of V30 which, in turn, are controlled by the PRF selection circuit. Thus, the frequency of the multivibrator output is controlled by the sweep gate circuit and the pulse width varies with the PRF of the equipment.

The output of the multivibrator, a positive square wave—the leading edge of which coincides with the end of sweep time—is shown by waveform (5) in figure 9-14. Like the output of the sweep gate multivibrator, this square wave is

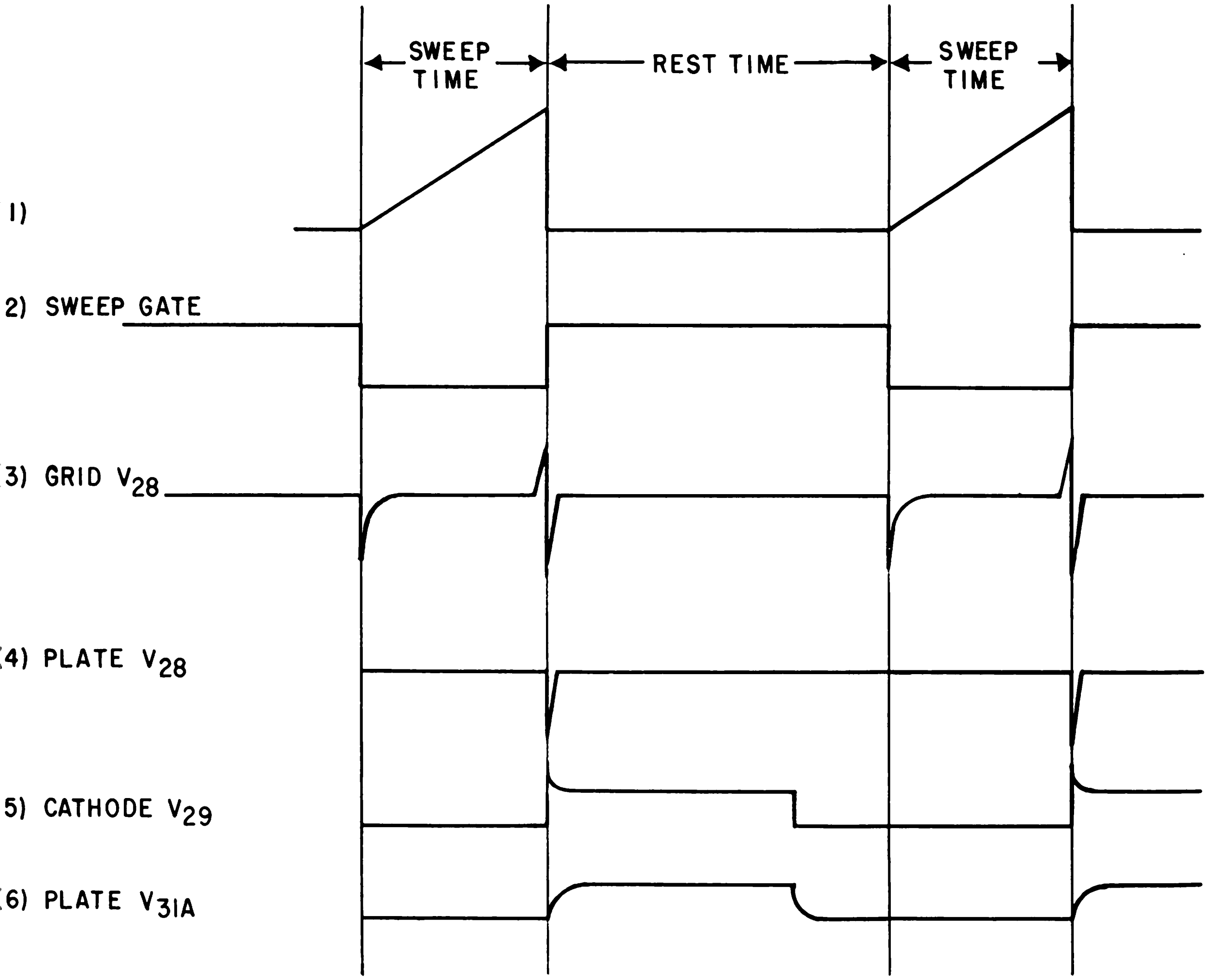


Figure 9-14.—Compensating gate waveforms.

AQ.24

ed as a gating pulse by the compensating gate amp circuit.

mpensating Gate Clamp

Before discussing how the compensating gate amp circuit utilizes the gating pulse, firstconder its static state. Referring to figure 9-13, te that R111 and R110 form a voltage divider tween minus 300 volts and the cathode of V16 ich is approximately positive 6 volts in static ndition. The plate of V31A is held slightly posve (approximately 1 volt) with a small current wing through R102 and V31A.

When the equipment is operating, a sawtooth ltage of approximately 20 volts in amplitude is developed across the sweep driver cathode resistor. This 20-volt increase will increase the charge on C54 and the current through V31A. The voltage to which C54 will charge will be proportional to the amplitude and duration of the sweep sawtooth.

As the sawtooth is terminated, the compensating gate multivibrator produces a positive square wave (discussed previously) which cuts off V31A. This effectively connects the capacitor C54 to the grid of the first compensating gate amplifier. Thus, the voltage across C54 which is proportional to sweep amplitude is used to generate the compensating gate voltage.

A summary of the action of the circuit is as follows:

1. C54 is charged to a voltage that is proportional to the amplitude of the sweep sawtooth.
2. At the end of sweep time the compensating gate circuit is triggered and a square wave gating pulse is generated.
3. This square wave is used to disconnect V31A from the circuit.
4. The voltage across C54 is now applied to the grid of the first amplifier.
5. At the end of the gating pulse, V31A conducts and the circuit is ready for its next sweep.

Study the waveforms in figure 9-14 carefully and insure that the time relationship of each waveform is understood.

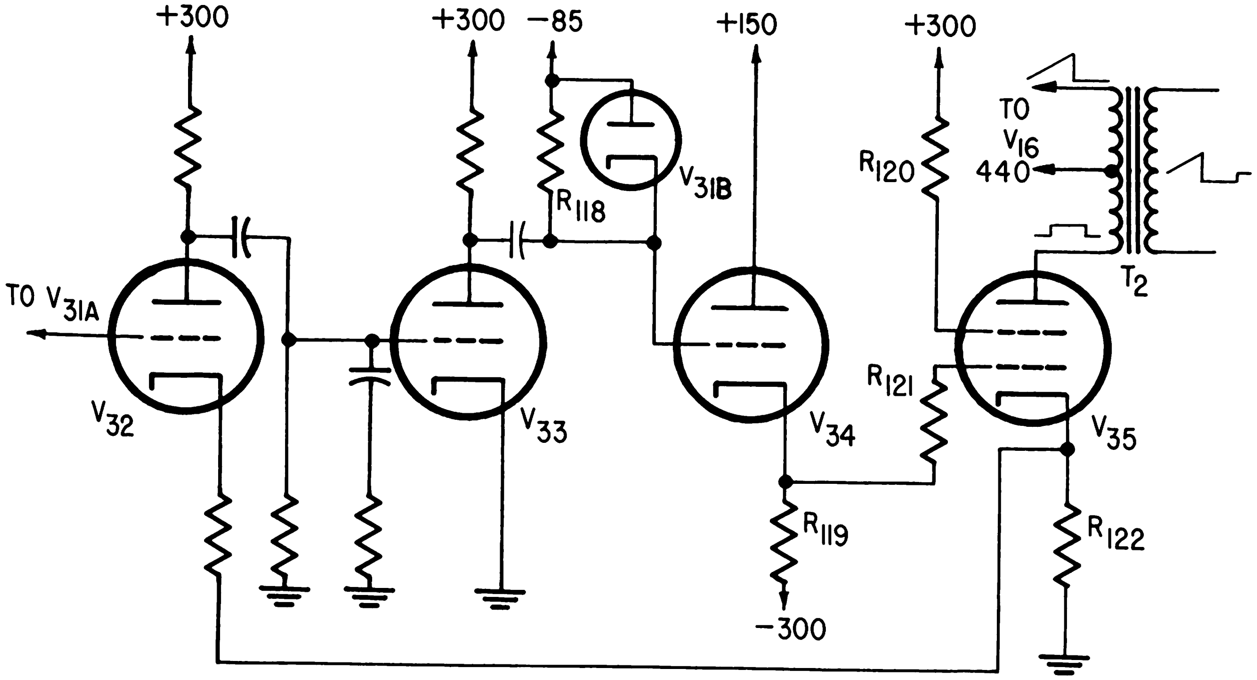
Compensating Gate Amplifier

The compensating gate amplifier consists of two voltage amplifiers and a cathode follower. (See fig. 9-15.) Their function is to amplify the compensating gate pulse to the proper level to drive the compensating gate driver. The amplifier is similar to the sweep amplifier discussed in the previous section and therefore is discussed only briefly.

The positive gate on the grid of V32 is amplified and inverted, and fed to the grid of V33. The gate is again amplified and inverted and appears as a positive gate on the grid of the cathode follower V34. The diode V31B is employed as a clamper to insure that each gate starts from the same static potential. The grid of the cathode follower is connected to a negative 85 volts, permitting an input signal of considerable amplitude without distortion. It should be noted that inverse feedback from the cathode of the driver to the cathode of the first amplifier is used to improve the shape of the compensating gate output.

Compensating Gate Driver.

The driver V35 is identical to the sweep driver V16. Its output is a square wave of the same area as the sweep waveform. Although the compensating gate is of the same polarity as the sweep voltage, it is inverted since it appears at the opposite end of the primary winding of T2.



AQ. 25

Figure 9-15.—Compensating gate circuit, part 2.

Thus, the compensating gate is combined with the range sweep sawtooth voltage as shown in figure 9-16.

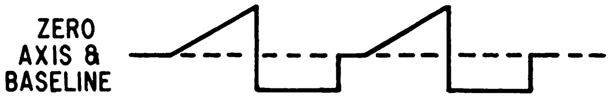


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Figure 9-16.—Range sweep sawtooth and compensating gate voltage waveform.

INTENSITY GATE CIRCUIT

The purpose of the intensity gate circuit is to provide a means of unblanking and blanking the indicator at the proper time. However, before discussing the intensity gate circuits, consider the circuits that provide it with a trigger or gating pulse. When the equipment is using a delay, the intensity gate circuit is triggered by the output of the sweep gate multivibrator. However, this pulse is not usable without prior amplification. This is accomplished by the sweep gate amplifier and the sweep gate cathode follower.

Sweep Gate Amplifier and Cathode Follower

The sweep gate amplifier V27 is conducting during static condition. (See fig. 9-17.) A negative square wave is applied to its control grid during sweep time, cutting it off. This produces a positive-going square wave which is direct-coupled to the grid of the sweep gate cathode follower V26. Its output, taken from the cathode, is fed to pin 4 of relay K15B. Thus, when the equipment is using a delayed operation, the intensity gating circuit is controlled by a positive square wave of the same time relationship as the range sweep sawtooth.

Intensity Gate Output

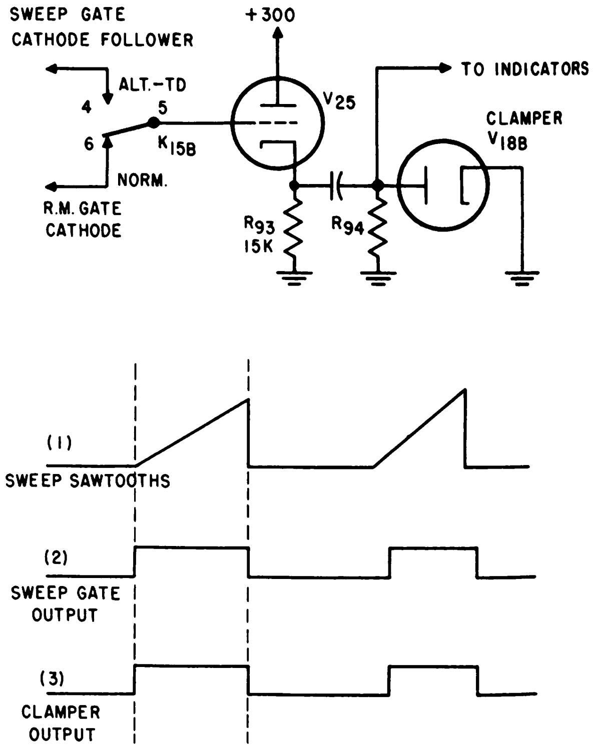
The intensity gate output V25 (fig. 9-17) is a cathode follower whose input comes from either the sweep gate output (just discussed) or the rangemarker gate circuit, depending on the type of operation employed. In either case the operation of the intensity gate stage is identical. Its input is a positive-going square wave, beginning and ending with sweep time, which causes V25 to conduct heavily. The increased current flow develops a positive square wave at the output, which is coupled to the intensity gate clamp circuit.

Intensity Gate Clamp

The intensity gate clamp V18B is a negative clamper. It clamps the positive portion of the square wave from V25 at the zero reference voltage. This effectively provides a negative square wave for blanking the indicator's sweep when there is no sweep voltage fed to the indicator (flyback). Waveform (3) illustrates the waveform fed to the indicator.

TRANSISTORIZED SWEEP CHAIN

The sweep circuits in figure 9-18 provide the indicator tube with a sawtooth output voltage for



AQ. 27

Figure 9-17.—Intensity gate circuit and waveforms.

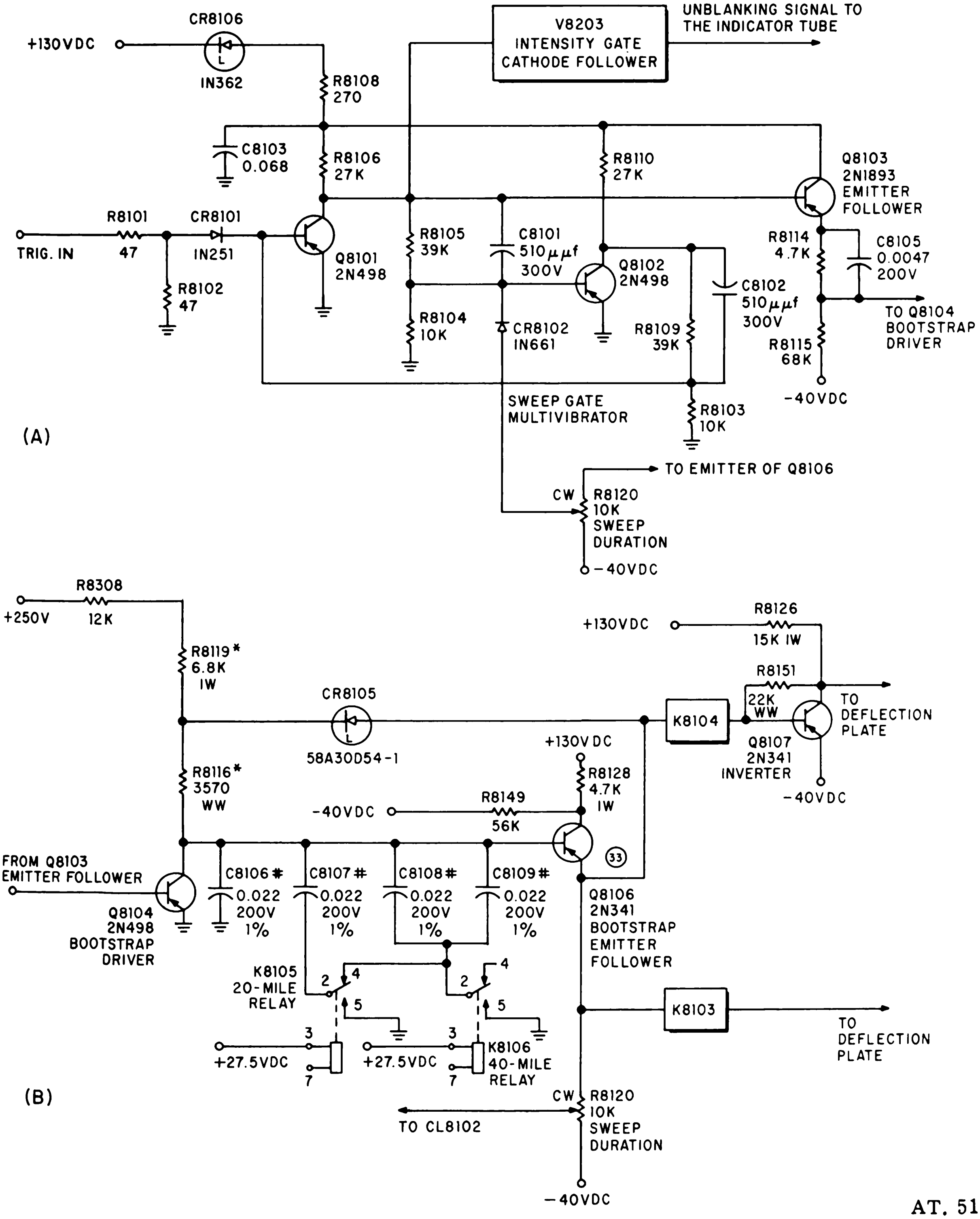


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Figure 9-18.—(A) Sweep gate multivibrator; (B) sawtooth generator.

the deflection plates and an unblanking signal for the cathode. The basic circuits are discussed in Basic Electronics, Vol. 2. This section is concerned with the operation of the basic circuits as a sweep chain. (See fig. 9-18 (A).)

Q8101 and Q8102 form a bistable multivibrator. In the initial state, Q8101 is nonconducting and Q8102 conducts. At the time the magnetron is pulsed, a positive sync trigger is applied to the base of Q8101, initiating conduction in Q8101 and shutting off Q8102. This develops a negative step-function output at the collector of Q8101 which is applied to the base of emitter follower Q8103. The negative step-function is reproduced at the emitter of Q8103 and applied to the base of Q8104. (See fig. 9-18 (B).)

The collector of Q8104 is connected through R8116 and R8119 to + 250 volts d.c. In the initial state, Q8104 conducts, dropping the collector voltage. When the negative output from Q8103 shuts off Q8104, the collector potential of Q8104 rises. C8106 then begins charging through R8116 and R8119, providing a positive-going input to the base of Q8106 which reproduces the positive-going input at the emitter. The output from the emitter is fed back through zener diode CR8105 to the high-potential side of R8116. As C8106 charges, the potentials at each end of R8116 rise at the same rate. As a result, the voltage drop across R8116 remains constant, forcing C8106 to charge at a constant rate. Thus, a positive, linear sawtooth input voltage is developed at the base of Q8106.

C8106 charges at a rate to provide a sweep voltage for a 10-mile sweep. To provide for a 20-mile sweep, the capacitance is doubled by connecting C8107 to ground through normally open contacts on relay K8105. This puts C8107 in parallel with C8106, doubling the capacitance and the charging time. To provide for a 40-mile sweep, C8108 and C8109 are added to the parallel group.

The emitter of Q8106 is connected to a regulated-40-volt supply through sweep length potentiometer R8120. The potential at the pickoff arm of R8120 is connected through reverse biased diode CR8102 to the base of multivibrator Q8102. When the sweep voltage rises to a potential which will bias CR8102 in the conducting direction, Q8102 will conduct, cutting off Q8101 and ending the sweep cycle. Q8101 will remain cut off until the next sync pulse arrives.

Q8106 provides a positive, sawtooth output voltage at the emitter. This output is coupled to one of the deflection plates through relay contacts and a cathode-follower deflection voltage circuit.

The positive sawtooth output of Q8106 is also applied to the base of Q8107 through contacts on relay K8104. Q8107 amplifies and inverts the positive input, providing a negative sawtooth output at the collector. The negative sawtooth output is coupled to the deflection plate which is opposite the one connected to the positive sawtooth output from Q8106. Thus, the positive sawtooth output from Q8106 and the negative sawtooth output from Q8107 provide a push-pull deflection voltage for the deflection plates. (See fig 9-18 (A).)

V8203 provides an output which permits electron gun beam current to flow during the sweep cycle but blanks the indicator tube in the period between sweep cycles. The cathode of V8203 is connected to the electron gun cathode. In the period between sweep cycles, the cathode potential of V8203 biases the electron gun cathode so far positive relative to the grid that electron gun beam current cannot flow even through a video signal were applied to the control grid.

It will be recalled that on the arrival of a sync trigger pulse at the base of sweep-circuit multivibrator Q8101, a negative output is developed at the collector to initiate a sweep cycle. The negative output from Q8101 is also applied to the grid of the unblanking cathode follower, V8203. This drives the cathode of V8203 more negative at the beginning of the sweep cycle which reduces the electron gun cathode bias relative to the grid to a value which will permit beam current to flow when a positive video signal is applied to the control grid. At the end of the sweep the negative gate voltage is removed from the grid of V8203, and the cathode output again blanks the indicator tube.

MARKER SYSTEMS

Marker systems are used to enable the radar operator to determine the location of targets with great accuracy. This may be accomplished by causing visual guides to appear on the face of the scope. These guides or markers provide range and azimuth (bearing) of a target. Some systems present additional information that gives the operator the relative height of the target.

Markers are also used on equipment other than radar, for example—electronic countermeasures, loran, oscilloscopes, and many others. In these equipments, markers are used to determine pulse width, pulse spacing, pulse amplitude, and various other functions.

Early radars depended on the linearity of the scope sweep for accuracy in range. A rough range scale was etched on a transparent plastic plate and this was placed on the face of the scope. Present-day radars obtain range markers from a range marker circuit. This circuit consists of a stable oscillator that generates accurately spaced range markers which are used to modulate the electron beam in a PPI type scope. This type presentation causes intensity type markers to appear.

An A-scope may also utilize itensity type markers or the markers may be applied to the deflection circuits. The application of the marker to the deflection circuits causes pulse type markers to appear on the scope.

FIXED RANGE MARKER

This circuit uses a gated type ringing oscillator which produces range marks that are synchronized with the sweep. A circuit that illustrates this system is shown in figure 9-19.

The gating tube V1, because of positive bias, is normally conducting and producing a steady flow of current through L1. The flow of current through L1 maintains a magnetic field around the coil; thus, the tank circuit composed of L1 and C2 cannot oscillate. Simultaneously with the starting of the scope sweep a negative square wave is applied to the grid of V1, cutting the tube off and causing the magnetic field around L1 to collapse. The collapsing of this field shock-excites the oscillator. The circuit continues to oscillate throughout the duration of the negative square wave. The values of L and C, in the series-fed Hartley oscillator, are so chosen that the duration of each cycle of oscillation is equal to the time between the desired range marker spaces. The leading edge of each negative oscillation produces a range marker in the output of the circuit. V2 replenishes the losses of the tank circuit, thereby maintaining the amplitude of oscillation.

The peaking amplifier V3, that is normally conducting, is cut off by the oscillator's negative output. A high positive voltage at the plate

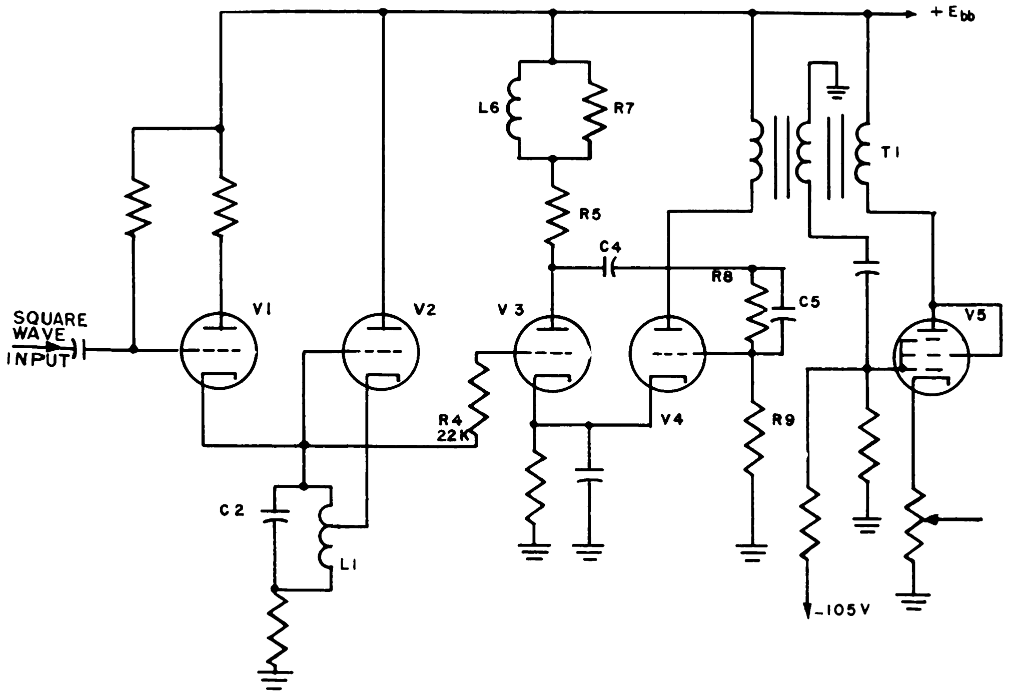

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Figure 9-19.—Ringing oscillator range marker.

of V3 is produced by the collapsing magnetic field around L6. Oscillations across L6 are prevented by damping resistor R7, thereby preventing possible double range markers on the scope. Positive oscillation of the grid signal causes limiting to occur in the grid of V3 due to R4 in the grid circuit. Therefore, the negative-going portion is the only part of the input wave that has an appreciable effect on the plate current of V3. The positive pulse output is coupled to the grid of V4 through C4 and C5. C4 functions as an ordinary coupling capacitor; C5 in conjunction with R8 acts as a fast coupling network. The leading edge of the output pulse from V3 contains high frequency components. These are coupled through C5 which bypasses R8; therefore, the complete leading edge of the output of V3 is developed across R9. This sharp rise in voltage on the grid of V4 causes it to draw current charging the lower plate of C5 negatively, since C5 and R8 have RC time of approximately 1 second. The charge due to grid current rapidly discharges through R8 and returns the coupling circuit to a static condition.

If only C4 were used to couple the sharp rise to the grid of V4 when the grid drew current, the grid side of C4 would go negative. Since the discharge path for C4 is long, it would soon assume an average charge and the coupled signal would be reduced to minimum. The blocking oscillator V5 is normally cut off by a fixed negative voltage on the grid. This circuit is triggered by the output of V4 which is coupled to the grid. Positive range marks are taken from the cathode of V5.

MOVABLE RANGE MARKER

Many present day radarscopes utilize the movable marker or range strobe. This system provides a continuously variable marker that may be used to aid the operator in quickly determining the accurate range of a target. Movable marker action may be incorporated in a radar system by using multivibrators or the phantastron time delay circuits which are discussed in Basic Electronics, Vol. 2. Another system whereby such marker action may be obtained is a timing circuit using a linear sawtooth and diode pickoff tube (fig. 9-20). This system is explained in detail in the following paragraphs.

The sweep generator tube V1, which is normally conducting, is cut off by the negative input square wave. When cut off, its plate voltage rises at a rate determined by the sweep capacitor C1. In order to obtain a linear sawtooth output it is necessary to use either the first ten percent of the charge or to add a bootstrap circuit to the sawtooth generator. This sawtooth waveform is applied to the plate of V2. V2 is normally cut off by the positive voltage on its cathode. The sawtooth rise applied to the plate of V2 eventually overcomes the cathode voltage and causes the diode to conduct. When this occurs the cathode voltage rises at the same rate as the plate voltage and is applied to the grid of V3. Tube V3, because of the transformer T1 in its plate circuit, then functions as a peaker amplifier. The output of V3 is applied to the grid of V4 and causes it to conduct momentarily. The current through the plate winding of T2, due to the conduction of V4, causes the single-swing blocking oscillator to cycle and produce the delayed pulse output.

The duration of the delay depends upon the voltage applied to the cathode of V2; this voltage is determined by the position of the potentiometer arm of R7. As the arm of the potentiometer is moved toward the more positive end, a higher voltage is then applied to the cathode of V2 and more time is required for V2 to start conducting, thus giving more delay before the pulse is produced. This delayed pulse is the movable marker that appears on the scope. Range is read from a mechanical counter or other indicating device which is mechanically coupled to the arm of the delay potentiometer R7. This counter is calibrated by adjusting the zero adjustment R10 and the slope adjustment R9. These potentiometers are positioned to provide the correct voltage across R7 so that the delay that is provided, dependent upon the location of its arm, is correctly indicated by the counter.

MOVABLE HEIGHT MARKER

The linear sawtooth delay circuit (fig. 9-20) may be used as the timing system for measuring target height with radar equipment. In order for it to apply to movable height markers, certain modifications must be made. The angle of elevation of the height finder antenna is referred to as ϕ. In the movable range marker (fig. 9-20), a fixed supply potential was used for the sawtooth generator, but when this circuit is used for height finding the supply voltage varies with the angle of elevation of the antenna. Thus, the slope of the sawtooth is proportional to sin ϕ. In this application the counter or other indicator that is connected to the delay potentiometer indicates the target's height.

The curvature of the earth may be neglected when determining height at short or medium ranges. The relationship between delay time and target height, or the time when the height marker appears on the sweep, may be expressed as follows:

$$T = \frac{2H}{C \sin \phi}$$

T equals time
H equals height
C equals speed of radio waves
ϕ equals angle of elevation

Since the slope of the sawtooth has been made proportional to sin ϕ, the time delay is inversely proportional to sin ϕ or, in other words, directly proportional to

$$\frac{1}{\sin \phi}$$

for a given diode bias.

TRANSISTORIZED MARKER CHAIN

The range-marker circuits in figure 9-21 provide 1,000-, 2,000-, or 3,000-yard markers. Generation of the marks commences at ringing oscillator Q1611-Q1612, which is excited into operation by the incoming delayed or remote

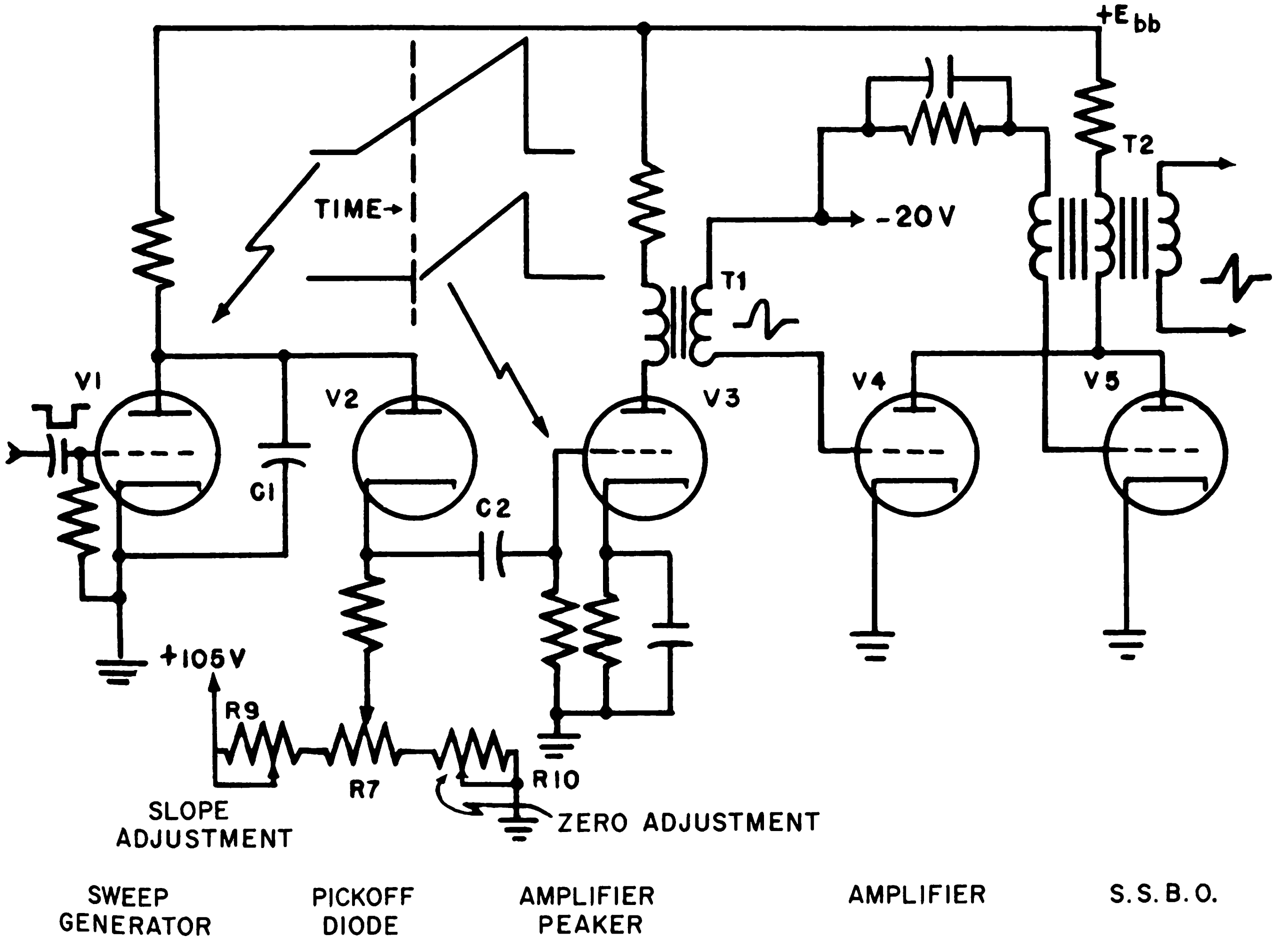

Figure 9-20.—Sawtooth type movable marker.

trigger pulse, thereby producing a 162-kHz sinusoidal output which is synchronized to the trigger pulse. Emitter follower Q1613 couples this output to countdown multivibrator Q1616-Q1617, which is thereby driven to develop a negative pulse train, the period of which is controlled by the setting of the range-mark selector switch (S1602) to obtain 1,000-, 2,000-, or 3,000-yard markers. The output from delay multivibrator Q1616-Q1617 is coupled through pulse-forming amplifier Q1614 to the indicator unit where the markers are amplified and applied to the indicator tube.

The ringing oscillator is a two-stage circuit whose first stage (Q1611) acts as a gate to turn its second stage (Q1612) on and off at the appropriate instants. During quiescent period, Q1611 is saturated by the forward bias developed by the network composed of R1636, CR1611, and R1696; and Q1612 is cut off by the reverse bias developed by the network composed of R1641, R1640, R1639, and L1601. Therefore, no output is developed by Q1612, which is essentially a Hartley oscillator connected in a common-emitter configuration. Upon the application of a trigger pulse, capacitor C1618 becomes positively charged, driving Q1611 to cutoff. This results in a sharp drop in current through the feedback portion of L1601 and therefore effectively excites the tank circuit consisting of L1601 and C1619. The resultant oscillatory currents alternately turn Q1612 on and off, producing a sustained train of oscillations at the tank-circuit resonant frequency, 162 kHz. After the trigger pulse passes, C1618 commences to discharge through R1636, thereby causing the reverse bias on Q1611 to reduce accordingly at a rate determined by the RC time constant of the C1618-R1636 circuit. Thus, when the cutoff level is reached Q1611 again becomes forward-biased and rapidly goes into saturation. This causes a surge of current through the feedback winding of L1601 which counteracts the effect of the oscillatory tank circuit current, thereby stopping oscillation. Since the gate derived by the discharge of C1618 is approximately 80 microseconds in duration, each time Q1611 is triggered, Q1612 produces 4 1/2 cycles of output. This output is coupled through emitter follower Q1613 as a drive signal for countdown multivibrator Q1616 - Q1617. Potentiometer R1639 controls the quiescent bias on Q1612, thereby permitting the amplitude of the output to be adjusted to a level sufficiently great to properly drive the countdown multivibrator.

Emitter follower Q1613 provides interstage buffering by isolating ringing oscillator Q1612 from countdown multivibrator Q1616-Q1617. This conventional circuit provides a 7.5-volt peak-to-peak output which corresponds to each burst of oscillator output. The output coupling circuit composed of C1621, R1644, and CR1612 shifts the average output level to zero (ground) and clips the negative-going portions of the signal, thereby allowing only the positive half of each sine wave to reach the countdown multivibrator.

The countdown multivibrator receives a high-frequency positive trigger input signal from the ringing oscillator corresponding to 1,000-yard intervals. The input signal results in an output configuration coincident with either the 1,000-, 2,000-, or 3,000-yard marks, depending upon the position of switch S1602.

During the quiescent state, transistor Q1616 is normally on and Q1617 is cut off. When a positive pulse is applied to the base of Q1616, the transistor is cut off and the negative voltage at the collector of Q1616 becomes more negative. This negative-going voltage is applied to the base of Q1617 through C1624, thus increasing the forward bias. The Q1617 collector voltage now decreases in a positive direction, and a portion of this voltage is coupled back to the base of Q1616.

Switch S1602 selects the time the multivibrator remains in a quasi-stable state (Q1617 saturated and Q1616 cut off). It can be seen that switch S1602 will set in different RC time constants due to the action of C1625 and C1626 and resistors R1653 through R1655 in the switch circuit. Thus, when capacitors C1625 and C1626 discharge, the base of Q1616 will become more negative. When the base of Q1616 becomes negative, Q1617 once again conducts. Transistor Q1616 is now cut off. This condition will be maintained until another pulse triggers the circuit.

The input circuit to the pulse-forming amplifier Q1614 consists of an RC differentiating network, R1646-C1622, which couples the incoming, negative, square wave from countdown multivibrator Q1616-Q1617 to the base of Q1614. Therefore, due to the action of R1646 and C1622, Q1614 is alternately driven to saturation and cut off in step with the leading and trailing edges of the input signal. This results in the development of a similar, coincident pulse train at the emitter of Q1614. Diode CR1613 clips the positive peaks resulting from the input differentiation, thereby allowing only the negative pulses to be passed on to marks mixer Q1615.

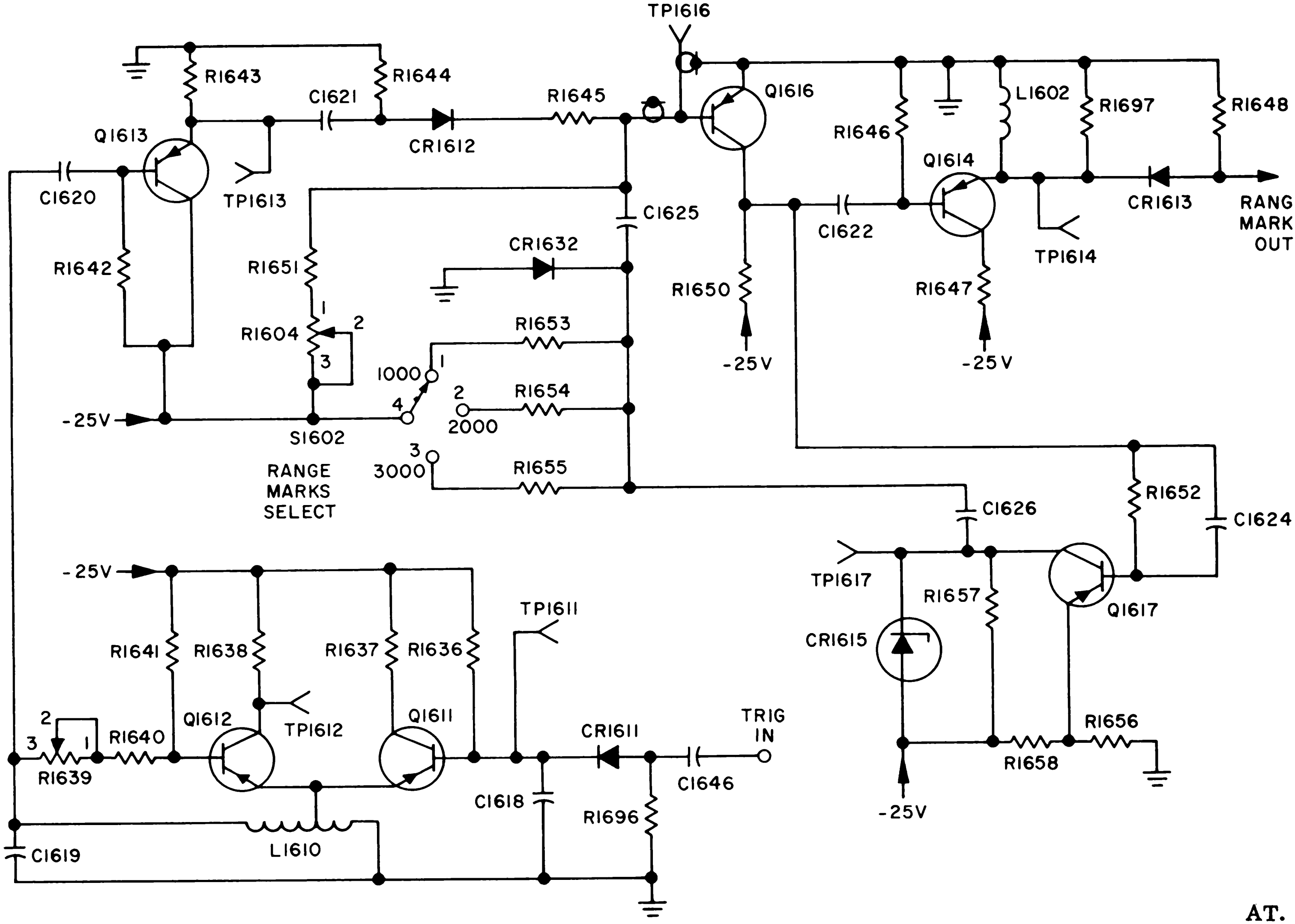

Figure 9-21.—Transistorized range-marker chain.

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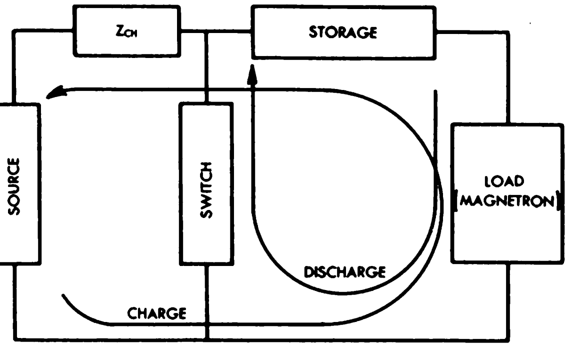
RADAR TRANSMITTERS

The transmitter functions to provide RF ergy, often at extremely high power, for short ervals of time. The science of radar requires t the frequency of this energy be in the crowave region. The high-power oscillator t produces the RF carrier is usually a gnetron.

DULATING THE MAGNETRON

The modulator for the magnetron serves a uble purpose–it determines the waveform of output pulse, and it stores energy between lses and releases it through the magnetron ring the pulse.

The basic circuit for a magnetron modulator shown in figure 9-22. In this circuit the orage element is charged through the charging pedance Z_{ch} and the load. It is discharged rough the the load when the switch is closed. examining this circuit, you can see that osing the switch also completes a circuit ntaining the power source and Z_{ch}. This has tle consequence, however, since the switch closed for only a microsecond or so at a time d Z_{ch} is large enough to prevent any damage. is well to become familiar with the components some of the modulator circuit elements which e shown as blocks in this circuit. In the odulator, the source from which the storage ement is charged may be either a d-c voltage an a-c voltage. The magnetron requires a voltage of 10 to 15 kilovolts or higher for proper operation. In some types of equipment a transformer is used between the storage element and the magnetron to step up the voltage, while in many others a direct connection is made between the storage element and the magnetron. Actual charging circuits are discussed in a later section dealing with line-pulsing modulators. In these circuits the charging impedance may be a high resistance or a high inductance, or both. Its purpose is to control the charging time for the storage element and to prevent short circuiting of the source during the pulse.



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igure 9-22.–Basic circuit for storage and release of energy in a modulator.

SWITCHING DEVICES

Switches for controlling the discharge time of pulse-forming networks may be of various types. Three types that will be discussed in this chapter are the ROTARY SPARK GAP, GAS DIODE, and THYRATRONS.

Rotary spark gaps are generally not used in aviation equipment because they are instable, must be enclosed in a pressurized chamber, and different repetition rates are difficult to obtain.

Gas diodes are used in some high-powered modulators. Figure 9-23 illustrates a gas diode type switch in which two cold cathode gas diodes are used. Some equipments use more than two of this type diode. These tubes are connected in series and an equal resistance is connected in parallel with each so that the high voltage will divide equally across each tube. This division prevents the voltage across either tube from becoming high enough to cause the tube to conduct.

As illustrated in figure 9-23, the trigger pulse is applied across one diode and causes it to conduct. This conduction causes the triggered diode to appear as a closed switch which connects the full high voltage across the other diode and causes it to conduct. The conduction of this tube closes the network circuit. This circuit remains closed until the storage network discharges to the point where the diodes deionize. At this time the storage network begins to recharge.

The thyratron is the more common switching device utilized in modulators. It is operated at cutoff until a positive trigger pulse is applied to the grid. The tube then conducts until the network circuit becomes discharged to the point that the thyratron de-ionizes and the grid

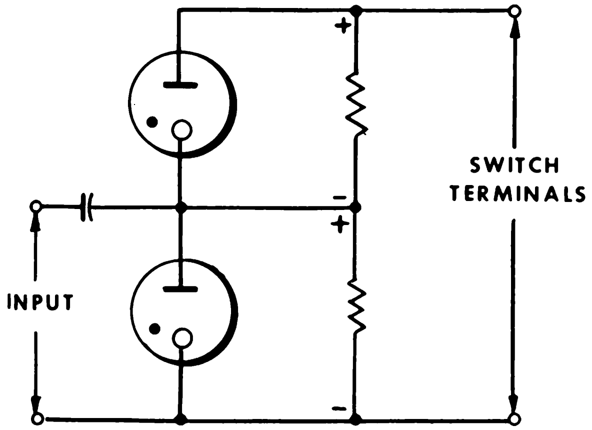

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Figure 9-23.—Gas diode switch.

regains control. The most common thyratron of this type is the HYDROGEN THYRATRON. While the gas diodes require an extremely high trigger voltage, the hydrogen thyratron requires a much lower voltage, approximately 30 to 100 volts. The normal life of this type of thyratron is expected to be about 900 hours; tube life is influenced by repetition rate and not pulse widths, providing the widths do not exceed 5 microseconds. The two advantages of the thyratron switching system are the accuracy of the firing time and the fact that the thyratron is not affected by the impedance of the trigger source.

PULSE-FORMING NETWORKS

The pulse-forming network consists of a series of coils and capacitors in an arrangement like that shown in figure 9-24. There are other arrangements for the elements in the PFN, but the arrangement shown is the most common. Most pulse-forming networks have a CHARGING CHOKE in series with the input. The choke is series resonant with the line and isolates the power supply from the switching device during discharge time. The LC constants in the network are carefully selected to provide a pulse of the proper shape and duration. The coils and capacitors must be rated to withstand the high voltages and currents they encounter in building up the high-powered pulse.

The PFN and charging choke are designed so that their combined impedance matches the output load as nearly as possible when the network is switched. The output line therefore appears as an infinitely long transmission line when the switch is closed. This reduces reflections in the charging circuit during the discharge interval. During the charging time, however, when the switch is open, the network is resonant. It can be shown that when a voltage is suddenly applied to an inductance and capacitance in

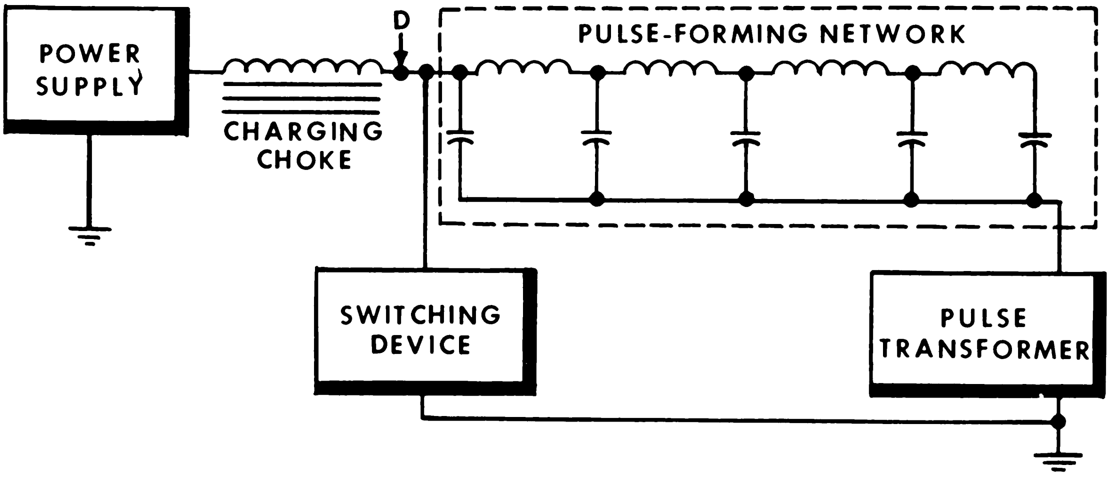

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Figure 9-24.—Schematic diagram of a typical pulse-forming network and charging choke.

series, the voltage at the resonant frequency of the circuit oscillates in such a manner as to give a sine wave, the amplitude of which is almost twice the applied voltage.

For maximum voltage production the pulse recurrence frequency should be equal to twice the resonant frequency of the charging circuit. To permit operation at more than one repetition rate, a charging diode must be connected in series with the charging choke. This diode would be connected at point D in figure 9-24. Figure 9-27 shows a multi-PRF modulator using a charging diode. The pulse-forming network is thus prevented from discharging after the maximum oscillation is reached. The diode also causes some additional damping in the circuit, so that the maximum value is slightly less than the original maximum value of almost twice the value of the d-c supply.

Because the diode maintains the voltage at practically twice the d-c supply for a considerable time the interval between times of closing the switching device can have any value greater than a half cycle of the charging oscillation.

The output voltage pulse from a d-c resonant charging network is about half the voltage to which the network is charged because the line impedance and load impedance are equal. Since the network is charged to nearly twice the supply voltage and the output pulse voltage is half the network charge, the usable voltage in the output pulse is about 0.9 of the supply voltage.

This type of pulse network is usually sealed in a metal box filled with oil which acts as an insulator. For that reason it is sometimes called a POTTED NETWORK. It is impossible to replace components in the line. Some lines using only a few elements are not potted. These do not generally give as nearly a rectangular output pulse, due to the smaller number of sections.

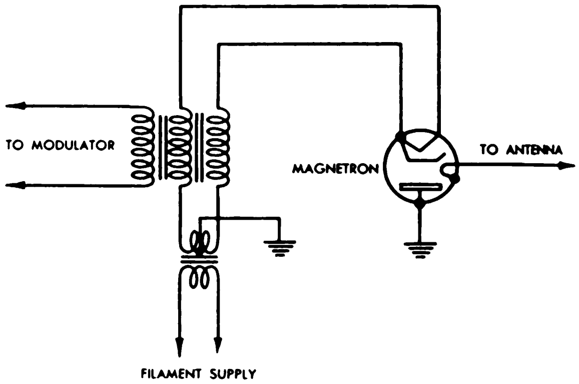

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Figure 9-25.—A transformer with two secondaries makes possible the grounding of the filament transformer secondary.

THE PULSE TRANSFORMER

In the circuits discussed thus far the load can be a magnetron and its associated circuits or the primary of a pulse transformer which has its secondary connected to the magnetron. The use of a high-voltage step-up transformer to furnish voltage for the magnetron makes possible the use of lower voltages in the pulse-forming network and thus simplifies the insulating problem. An advantage in using a transformer with two secondaries (bifilar windings), as shown in figure 9-25, is that it avoids having high voltage in the magnetron filament transformer. The bifilar windings have the same voltage induced into each since they are wound side by side. This winding makes it possible to connect a filament transformer, without high-voltage insulation, to the heater of the magnetron and to couple the high-voltage pulse between the cathode and plate.

A third need for the high-voltage pulse transformer is matching impedances, particularly where the radar antenna is remote from the set itself. Since the use of long transmission lines between the magnetron and the antenna makes the magnetron's operation somewhat erratic, it is desirable to have the magnetron near the antenna. This necessitates the use of long lines to carry the modulator pulse to the magnetron. In order to be able to use 50-ohm line for this purpose and still obtain an impedance match with the impedance of the magnetron (approximately 1,000 ohms), it is necessary to use a 4 1/2 to 1 step-up transformer at the magnetron end.

The pulse transformer must be specially designed because there are very high frequency components present in a rectangular pulse of such short duration. The core is usually silicon steel and has laminations in the order of 0.003 inch in thickness. In general a good pulse transformer must have low leakage inductance, low interwinding capacitance, and high primary inductance.

TYPES OF MODULATORS

There are two types of modulators—the line-pulsing modulator and the driver-hard-tube modulator. The line-pulsing modulator stores energy and forms pulses in the same circuit element. This element is usually the pulse forming network. The driver-hard-tube modulator forms the pulse in the driver; the pulse is then amplified and applied to the modulator. The hard-tube modulator has been replaced by the line-pulsed modulator. The reasons for this replacement are that the hard-tube modulator has lower efficiency, its circuits are more complex, higher power supply voltage is required, and it is more sensitive to voltage changes.

The line-pulsed modulator is easier to maintain because of its less complex circuitry and, for a given amount of power output, it is more compact and light. Since it is the principally used modulator in aviation radar, it is the only type that will be discussed at great length.

Before discussing the line-pulsing modulator, it is well to consider briefly the various types of charging circuits and to note their advantages and limitations. To do this, study figure 9-26 which shows the various types of charging circuits.

In the d-c resistance charging circuit (A), the pulse line or storage capacitance is represented as C_{st}. It is charged through Rch to the value of the d-c voltage. During the pulse one-half of d-c voltage is applied to the magnetron (assuming the line impedance is matched to that of the magnetron) for a period of time determined by the line components. This is only 50 percent efficient. Therefore, it is necessary that the d-c voltage be twice the value needed for the magnetron. The time constant $R_{ch}C_{st}$ must be large in comparison to the period of the repetition frequency. This insures that the line will fully charge between pulses but will not discharge appreciably through the source and R_{ch} during the pulse.

In the d-c resonance charging circuit (B), resistor Rch is replaced by an inductance L_{ch}. As C_{st} charges, the current through L_{ch} builds up a magnetic field. This field causes current to continue after C_{st} is charged to E_{bb}. The charge will reach a peak of approximately 1.9 times E_{bb} after which it starts decreasing. If the modulator is triggered at the instant of maximum charge, the voltage applied to the magnetron is about 95 percent of E_{bb}. This necessitates that the resonant frequency of $L_{c}h$ and C_{st} be one-half the PRF of the radar. The firing time is very critical if advantage of the maximum voltage is to be obtained.

The difficulty encountered in the preceding circuit is overcome by adding a diode in series with the charging element. Circuit (C) prevents the line from discharging after reaching its peak. This means that the time of firing can occur any time after the peak is reached. Therefore, the frequency at which L_{ch} and C_{st} resonate is equal to or greater than one-half the PRF. The disadvantage of making the firing time less critical is that the voltage to which the pulse forming line charges is decreased by the drop across the diode to about 1.8 times Ebb. This makes the efficiency of this circuit about 90 percent.

Circuit (D) has the pulse line charging from an a-c source. In this circuit, the charging line is prevented from discharging by a diode in series with it. Further, in this circuit it is necessary that every trigger pulse come at a time when the diode plate is negative; otherwise the diode and the switch will short circuit the a-c source. Therefore,

$$Tr = -\ NT_{ac}$$

where

T_r = time between trigger pulses

N = 1 or some other whole number

T_{ac} = time of a cycle of the a-c source voltage

The voltage to which the line charges is almost the peak value of the a-c wave so that the efficiency is about 70 percent.

In circuit (E), the diode is replaced by the inductance L_{ch}. This inductance, along with C_{st}, forms a resonant circuit which is resonant at the frequency of the a-c supply voltage. In this circuit the switch may be closed at any peak of oscillations. Usually it is closed at the first peak. At this time the voltage is approximately π times the peak value of the a-c voltage. In addition $T_r = T_{ac} = 2\pi x \sqrt{L_{ch} C_{st}}$. If the switch is closed at the second peak, the voltage will be nearly twice as high. This type of charging gives voltages higher than the source voltage.

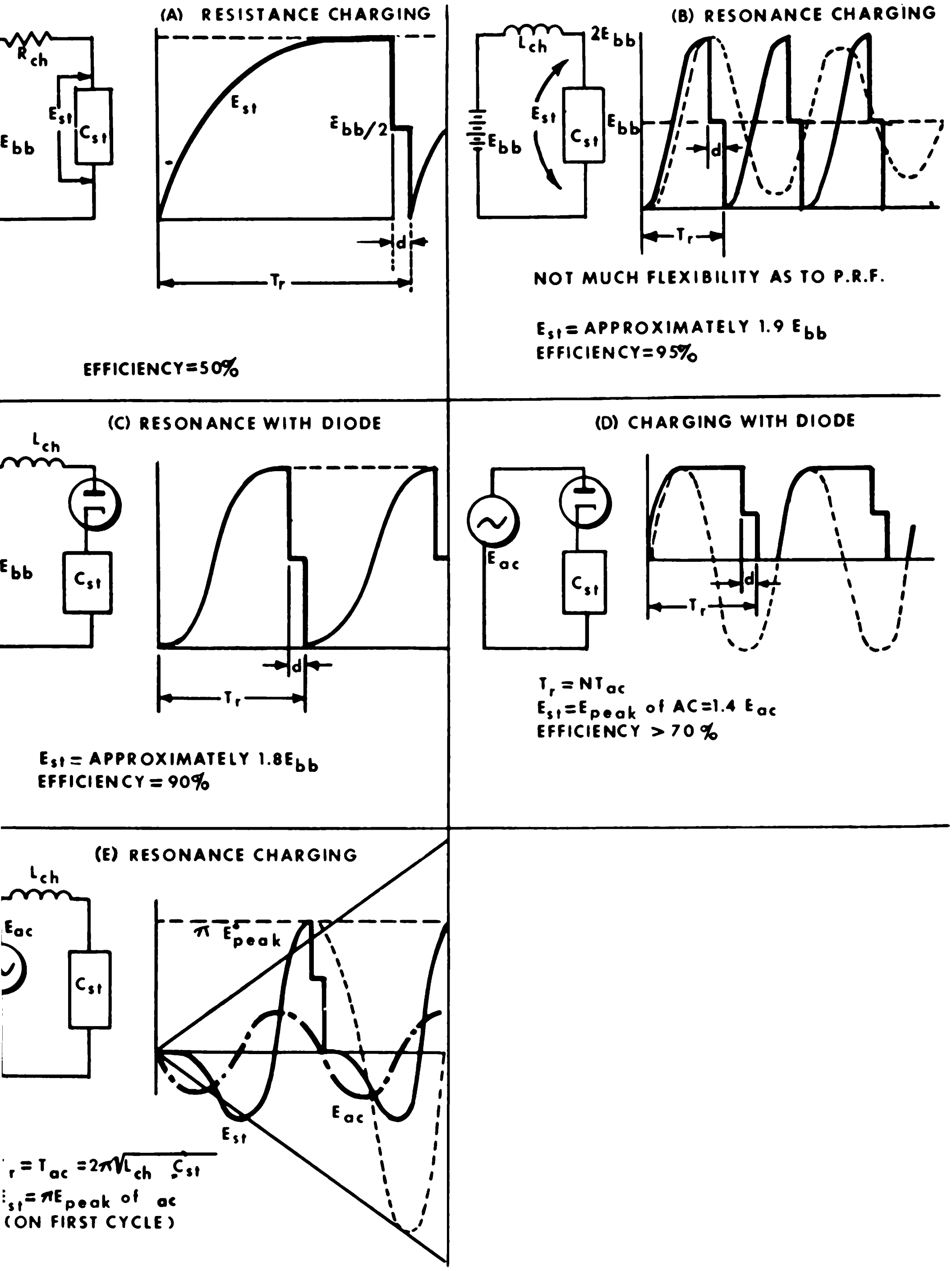

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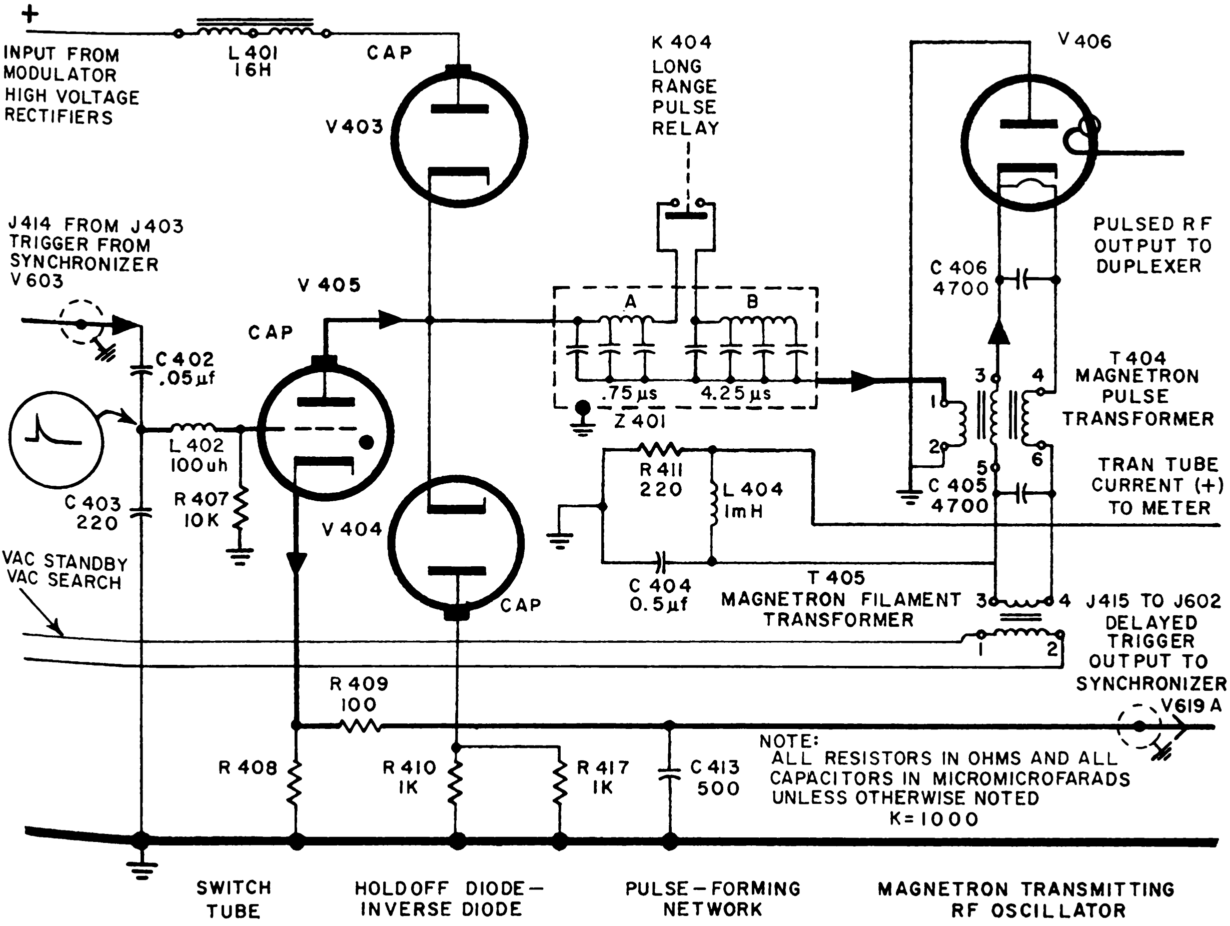
Figure 9-26.—Types of charging circuits.

Line-Pulsing Modulator

This discussion will serve a dual purpose—it will explain the theory of operation of a typical line-pulsing modulator and will also summarize the function of the various modulator components already explained in this chapter.

The modulator (fig. 9-27) is of the line-pulsing type. The pulse-forming network undergoes a charge-discharge cycle at a rate (PRF) which is established by the master-trigger generator and which is consistent with the pulse width in use and the maximum power capabilities of the transmitter. The modulator consists of artificial-line pulse-forming network Z401; hydrogen-thyratron switch tube V405; holdoff or charging diode V403; inverse-diode V404; resonant charging choke L401; and magnetron pulse transformer T404, the double-wound secondary of which supplies a pulse of power to the magnetron cathode circuit each time the line is discharged. The switching device which controls the discharge of the line is a hydrogen-thyratron tube controlled by the trigger from the radar's synchronizer.

When system power is applied, current to charge the pulse-forming network is drawn from the power supply through resonant charging choke L401 and charging diode V403. The flow of this current establishes a magnetic field in



+
INPUT FROM MODULATOR HIGH VOLTAGE RECTIFIERS
L 401 16H
CAP
V403
K 404 LONG RANGE PULSE RELAY
V 406
J414 FROM J403 TRIGGER FROM SYNCHRONIZER V 603
V 405
CAP
C 402 .05µf
A
B
.75µs
4.25µs
Z 401
C 406 4700
PULSED RF OUTPUT TO DUPLEXER
T 404 MAGNETRON PULSE TRANSFORMER
3
4
1
2
5
6
L 402 100uh
R 407 10K
C 403 220
V 404
R 411 220
L 404 1mH
C 405 4700
TRAN TUBE CURRENT (+) TO METER
115 VAC STANDBY 65 VAC SEARCH
C 404 0.5µf
T 405 MAGNETRON FILAMENT TRANSFORMER
CAP
J415 TO J602 DELAYED TRIGGER OUTPUT TO SYNCHRONIZER V619 A
R 409 100
R 408
R 410 1K
R 417 1K
C 413 500
NOTE: ALL RESISTORS IN OHMS AND ALL CAPACITORS IN MICROMICROFARADS UNLESS OTHERWISE NOTED K=1000
SWITCH TUBE
HOLDOFF DIODE—INVERSE DIODE
PULSE—FORMING NETWORK
MAGNETRON TRANSMITTING RF OSCILLATOR

AT.519

Figure 9-27.—A typical line-pulsing modulator and magnetron circuit.

the resonant charging choke. Charging is rapid up to the point at which the pulse-forming network charge nearly equals the peak power supply voltage, approximately plus 2,500 volts d.c. The rate of charge drops sharply, and the magnetic field built up in the resonant charging choke collapses. By this self-inductance, a voltage approximately twice the power supply peak voltage is rapidly established. The tendency of the resonant charging choke to oscillate is halted abruptly at its first positive peak by the rectifying action of the charging diode and the pulse-forming network is held at this high potential. Discharge of the capacitors within the pulse-forming network is prevented by charging diode V403. Inverse-diode V404, and thyratron switch V405 are inoperative and hence appear as infinite impedances and do not provide a discharge path for the network.

The master-trigger generator in the synchronizer supplies a trigger voltage to the grid of the thyratron switch tube through the d-c blocking capacitor C402. When triggered the switch tube ionizes and provides a closed circuit for the discharge of the pulse-forming network. This discharge continues for a definite period of time at a constant rate, determined by the constants of the pulse-forming network. A negative square-shaped pulse is impressed across the primary winding of the magnetron pulse transformer T404. The width of the transmitter pulse varies in a manner determined by the number of sections of the pulse line in use, as determined by the long-range pulse relay K404. Since the primary of transformer T404 is matched with the 50-ohm surge or characteristic impedance of the pulse-forming network or line, there is an equal division of voltage between these two units. Approximately 2,500 volts is impressed on the primary of T404. The turns ratio of T404 causes a voltage step-up of 1 to 5. Thus a negative pulse of approximately 12 kilovolts is placed on the cathode of the magnetron V406. The peak power of this pulse is in the order of 150 kilowatts. Output of the magnetron approximates 50 kilowatts due to losses in this tube and the associated circuits.

Gas bursts (arcing) occur occasionally within the magnetron. This condition causes momentary pulse-transformer impedance mismatching, and a small voltage of polarity opposite to that of the modulator pulse may appear across the pulse-forming network after the pulse. This small reverse voltage is in series with the power supply voltage at the start of the next charging cycle. Hence the total voltage available to produce the charging oscillation is increased, and the pulse-line voltage may build up to a value great enough to break down the thyratron. This condition is overcome by connecting inverse diode V404 in parallel with the thyratron. The diode bypasses the reversed charge of the pulse-forming network.

The pulse-forming network is composed of aircore inductors and mica capacitors. It is divided into two sections of artificial transmission line, all within the same container. Each part is a complete network. The connection of the two parts by relay K404 increases the width of the pulse. When only the first section Z401-A is in use, 0.75-microsecond pulses are generated. Addition of the second section increases the pulse period by 4.25 microseconds. With both sections connected, pulses of 5.0-microseconds duration are generated.

During long-range search operation relay, K404, is energized; thus both sections of Z401 are connected in the circuit to provide a 5.0-microsecond pulse.

Resonant charging choke L401 not only doubles the pulse-system voltage before firing, but it effectively isolates the power supply from the rest of the modulator during the relatively short periods of pulse duration. It also prevents the power supply from shorting through the switch tube during de-ionization.

Resistor R407 functions as a grid leak for the thyratron switch tube. Capacitor C403 and choke L402 form a filter network to prevent the reflection of the switch tube transients into the synchronizer. Switch tube current, flowing through the cathode resistor R408, generates a trigger pulse which is used for synchronizing the range mark start-stop multivibrator located in the synchronizer. Resistor R409 and capacitor C413 improve the trigger shape by removing ripple at the top of the pulse.

The cathode of the magnetron is internally connected to one side of the filament line. Input to the magnetron is applied by the modulator through the magnetron pulse transformer T404. The design of the pulse transformer provides two secondaries of similar electrical characteristics, one in each leg of the magnetron filament supply. This bifilar secondary winding maintains an equal and in-phase pulse voltage on both sides of the filament and effectively isolates the high-voltage modulator pulse from the low-voltage magnetron filament transformer T405. Capacitors C406 and C405 compensate for slight electrical differences between the pulse transformer output windings to prevent the appearance of high pulse voltages across the filament.

The d-c plate current of the magnetron flows through the cathode circuit of V406, pins 3 and 5 of the pulse-transformer, L404 and the 220-ohm resistor R411. Coil L404 (1 millihenry) blocks peak pulses but passes average current through the magnetron current meter. Capacitor C404 offers a low impedance to magnetron pulses and integrates them for metering. Negligible current is generated within the magnetron during quiescence, but the average of d-c current summed over a period of pulsed operation is of high magnitude. Longer pulse periods at lower PRF tend to balance shorter pulse periods at higher PRF, resulting in a nearly uniform duty cycle regardless of the radar function being performed. Note that while 115-volts is applied to the magnetron filament transformer during standby it is reduced to 65 volts when the high voltage is applied to the modulator.

IMPEDANCE MISMATCHES

The function of the radar antenna system is to direct the RF energy pulses from the transmitter to the antenna array, radiate this energy in a directional (or nondirectional in some applications) beam, receive the returning echo, and direct it to the receiver with a minimum of signal loss. The radar antenna system includes the RF transmission lines (couplers, junctions, rotating joints, radiating collector array, and protective devices) from the transmitter and receiver to the antenna array. To insure efficient performance with minimum loss, the antenna systems are carefully engineered and must operate within specified limits. Improper coupling between RF lines and the antenna or transmitter, for instance, may produce an impedance mismatch resulting in a high voltage standing-wave ratio (VSWR) and a general reduction in system performance.

The VSWR is measured to insure that the ratio of the power transmitted by the magnetron to the power reflected back along the transmission line is within the specific limits. Any discontinuous change along an RF line, such as a sudden change in dimensions, a change in geometry introduced by a sharp bend or dent, or an obstacle in the line will produce a mismatch resulting in a high VSWR.

If trouble in the RF transmission line (between the magnetron and the antenna) is indicated, adjustment of the magnetron tuning control should be made while observing whether this improves the VSWR. If it does not, then determine if the trouble is on the antenna or transmitter side of the antenna switch (duplexer) in the following manner: With the magnetron operating into a dummy load, observe the VSWR. No marked improvement indicates that the trouble is on the magnetron side of the antenna switch, while a marked improvement indicates that the trouble exists on the antenna side. If an increase was noted in the VSWR, check the RF transmission lines for any of the common causes listed below, and for any other damage which might have occurred. Check the antenna also, since any bending in the antenna array could change its impedance and result in an increased VSWR.

Many RF transmission-line faults are visible and easily located; however, in some cases the trouble may be of such a nature that the defective part can be found only by making special tests.

Some of the most common causes of an excessive high VSWR are:

1. Moisture in the RF line.
2. Dented or bent line.
3. Burrs or poorly soldered joints.
4. Defective coupling joints.
5. Defective or distorted rotating joints.
6. Mismatched antenna.

TRANSMITTER SAFETY DEVICES

Generally, transmitter protection is present in four areas of the transmitter. These areas are the magnetron filament control circuit, modulator high voltage control circuit, transmitter overload circuit, and transmitter metering circuit.

Magnetron Filament Control Circuit

The purpose of this circuit is to allow the magnetron filament to reach the proper operating temperature prior to the application of a high voltage pulse from the modulator. The circuitry may vary from the simple time delay relay to the complex circuitry of some radar sets.

Modulator High-Voltage Control Circuit

In case of interlock failure or overloads, the primary power control is driven beyond the minimum voltage position which in turn opens a safety limit switch and the modulator voltage is removed.

Transmitter Overload Circuit

This circuit is designed to remove modulator primary power when either an excessive modulator current exists or whenever excessive reverse current flows through the reverse current relay. A manual reset circuit restores the operation of the transmitter.

Transmitter Metering Circuit

This is a visual safety system which indicates by lights and meters, magnetron filament voltage, magnetron plate current, modulator current, transmitter overload, operation of the time delay system, pressurization failure, and cooling system failure.

RADAR TRANSMITTER AND RECEIVER PERFORMANCE CHECKS

Radar transmitter and receiver performance checks, when compared to other electronics system checks, are much more exacting and somewhat more complicated. It is possible, for instance, to determine to some degree the satisfactory operation of a radio receiver by listening to the tone and observing how much the gain control must be advanced to obtain sufficient volume. However, unlike most radio communication equipment, radar systems cannot be tested by observation alone to determine whether their performance is satisfactory.

In the field of radar, reliance on visual observation alone to judge the range capability and other data accuracy has been found to be so inaccurate as to be completely valueless. Careful and precise performance testing is the only procedure that will determine whether or not a radar is operating at peak efficiency. Thus, the technician must become familiar with the techniques of checking a radar set to insure its proper performance.

There are many applicable radar test sets in use today. The most appropriate set or sets to use are usually prescribed in the Handbook of Service Instruction for each particular radar type. These tests sets are designed to indicate either relative or absolute measurements. Echo boxes such as the TS-488A/U are designed to indicate relative measurements of performance. It is a simple device to operate and possesses the advantages of being portable and not needing an external power source (other than the radar signal that is to be analyzed) for its operation. Thus, it is an ideal test unit for line maintenance.

Echo box operation is discussed in AT 3 & 2, NavPers 10317-D; therefore, the combination test set AN/UPM-32 is discussed in the remainder of this chapter. This set presents absolute measurements and can be used to make performance checks of the transmitter and receiver. The operation of this test set is covered in chapter 5 of this manual.

TRANSMITTER POWER

High peak power in a radar transmitter is desirable to produce a strong echo at long ranges. Low average power is desirable, as it enables the transmitter components to be made smaller and more compact with less regard for cooling. It thus becomes apparent that a low duty cycle is desirable. The peak power which a set is capable of developing is primarily a design consideration. It is dependent upon the interrelationship between peak and average power and between pulse width and pulse repetition time, or duty cycle. The relationships of peak power, average power, and duty cycle are described in Basic Electronics, Vol. 2A. A means of insuring optimum power performance is built into most radar sets by means of a control that adjusts magnetron current. The operator is thus able to adjust magnetron current to recommended optimum values.

See the simplified block diagram of the power-meter and frequency-meter circuits of the AN/UPM-32 in chapter 5 (fig. 5-10).

Input signals from the radar pass through a calibrated attenuator (DBM and ATTENUATION controls) in the microwave section to a temperature-compensated power monitor. The calibrated attenuator is used to set the power level in the power meter. The attenuator dial will then indicate the AVERAGE power in dbm (decibels relative to 1 milliwatt).

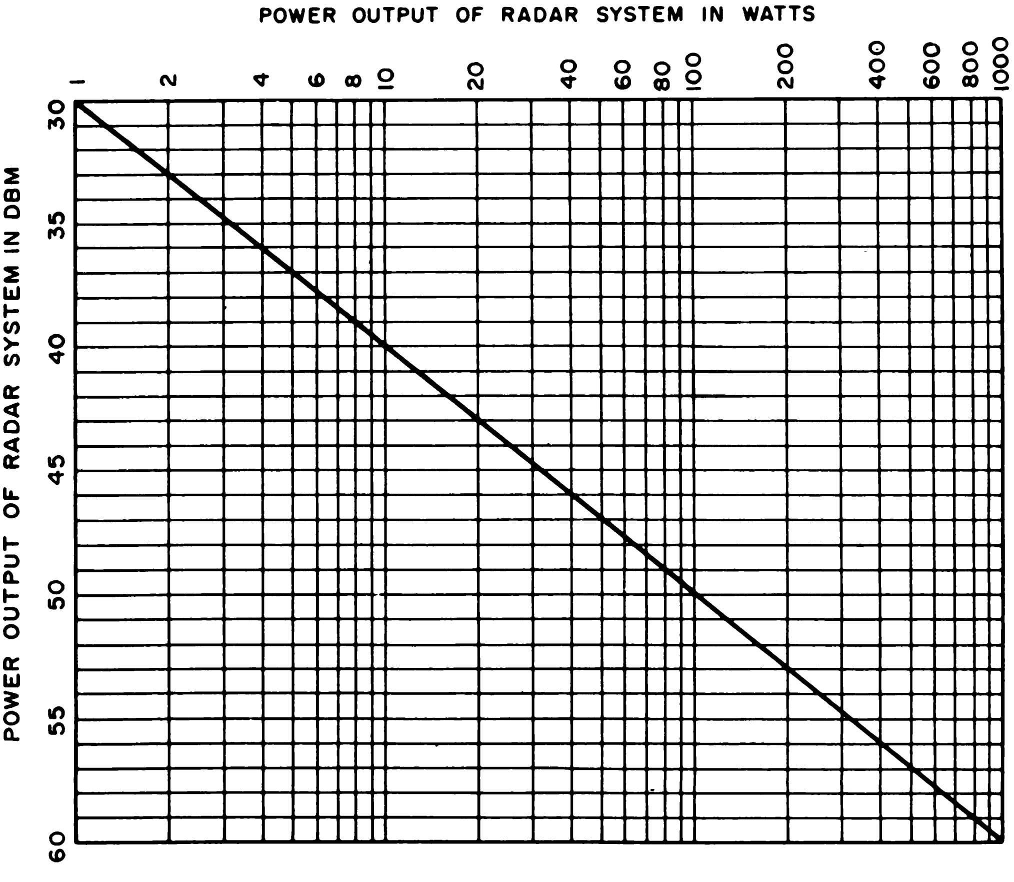
In making power measurements on a radar transmitter, there are two methods of sampling the power outputs of the transmitter. One method uses a pickup horn in front of the radar antenna. When this method is used, the placement of the pickup horn in relation to the antenna is extremely critical as air losses must be taken into consideration. A more satisfactory method is to connect the test set to the radar directional coupler with the special test set coaxial cable. This avoids the difficulty of measuring or calibrating air losses.

When the power (in dbm) is read from the attenuator dial, the losses must be added to this value. This is easily done by adding the attenuation (in db) of the directional coupler and the loss (in db) of the coaxial cable to the attenuator dial reading. The cable losses are usually indicated on a tag attached to the cable and usual values are about 1 db per foot of coaxial cable. The loss (in db) of the directional coupler is found on a tag or name-plate attached to the directional coupler and is usually 20 db or more.

Figure 9-28 shows a graph that can be used to convert power in dbm to average power in watts. This can also be accomplished mathematically by the equation

$$\text{dbm} = 10 \log \frac{P2}{P1}$$

where dbm is the total attenuation, P2 is the unknown output power in milliwatts, and P1 is the 1-milliwatt reference level.



A AT.520

Figure 9-28.—Conversion of power in dbm to power in watts.

SPECTRUM ANALYSIS

The measurement of frequencies employed in radar operation falls into two general categories, transmitter frequency and receiver frequency.

For the transmitter operation of any given radar system, a range of frequencies is assigned for that system. Therefore, the transmitter must operate within this band of assigned frequencies if normal operation is to be expected. Transmitter operation is restricted to a certain range of frequencies for the following reasons:

1. The associated waveguide tuning adjustments cover only a limited range of frequencies.
2. Interference between radars used for different types of services could result if all radars were permitted to operate in the same band. For this reason, airborne S-band and shipboard S-band radars usually operate in different parts of the band.

Radar transmitters may be either fixed in frequency or tunable. If the frequency of a fixed-frequency transmitter is measured and found outside the operating band, the magnetron should be replaced. Tunable transmitters may be adjusted to any frequency within the operating band. This is a very desirable feature where several radars are in use in a limited area—each one may be tuned to a different frequency to prevent interference. In addition, when jamming is present, a different frequency may be free of the jamming signal. Since the operating bands are fairly wide, transmitter frequency tests do not require extreme accuracy.

The transmitter frequency is readily measured by using the resonant cavity wavemeter section of the TS-757/UPM-32. The resonant cavity functions as an absorption type wavemeter. When tuned to the frequency of the transmitter, the cavity absorbs some of the microwave power. This reduction of power is indicated as a dip on the power monitor (meter) or synchroscope.

A convenient method of coupling the radar transmitter to the frequency meter is by use of the test set's special coaxial cable. One end is connected to the radar directional coupler, while the other is connected to the frequency meter input.

This wavemeter has a direct-reading dial for frequency indication. When the cavity is tuned to resonance, the frequency is indicated in megacycles per second in the FREQUENCY window. An attenuator is also included to prevent driving the power meter off-scale. While tuning the frequency meter, the control should be moved slowly. Otherwise it is possible to pass the resonance frequency without knowing it. The reason for this is that the power is detected by a thermistor which takes a short time to heat and react to the power applied to it.

The resonant frequency of the radar may also be indicated on the synchroscope. The reduction in power caused by absorption in the resonant cavity is apparent by a decrease in pulse amplitude on the CRT. This dip is usually easier to detect than the power meter. Final tuning, however, should always be done by the meter indication. Transmitter frequency may also be measured during spectrum observation.

Spectrum observation is the display of the magnetron's output on a synchroscope. By this method the technician may readily determine visually whether or not the magnetron is operating properly. Figure 9-29 shows an ideal spectrum of a pulsed magnetron. Note that the side lobes are very low compared to the main lobe, and that the main lobe falls off to zero on either side of the carrier frequency.

Figure 9-30 shows several examples of transmitter spectral displays that are less than ideal. In general, the distortion resulting from frequency modulation (fig. 9-30 (A) and (B)) is far more undesirable than distortion resulting from amplitude modulation (fig. 9-30 (C)). Both frequency and amplitude modulation may be present in a spectral display (fig. 9-30 (D)).

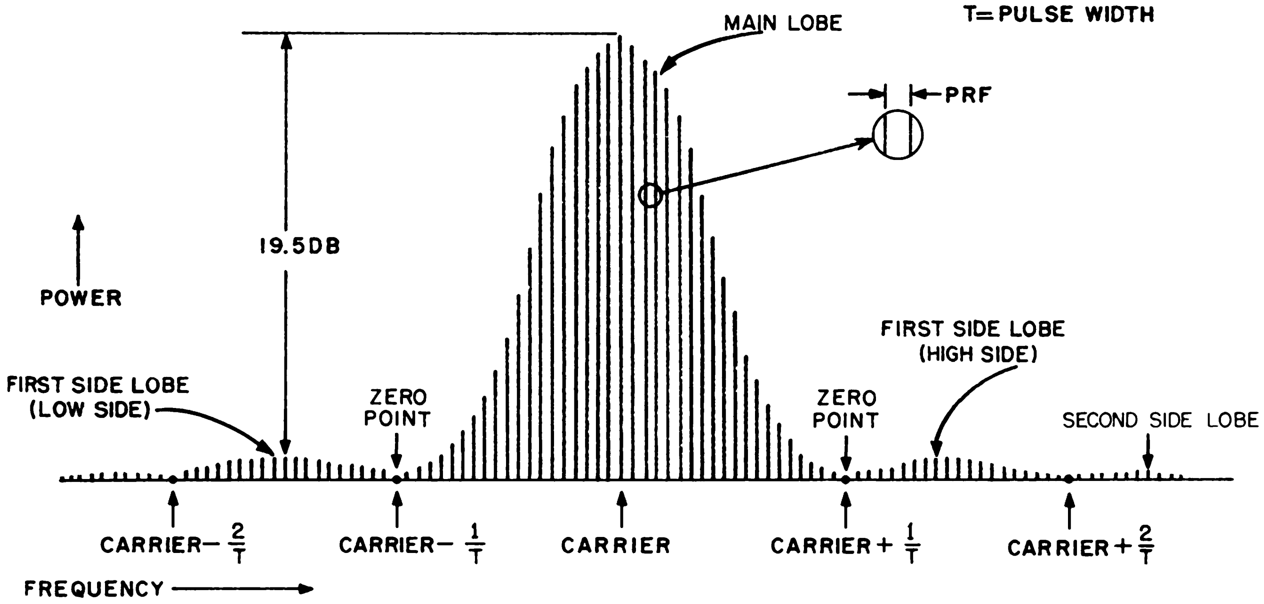
TRANSMITTER TROUBLES

The major troubles or indications of trouble met with in radar transmitters are incorrect operating frequency, poor spectrum, and low output. As a further complication, the troubles may occur intermittently.

Incorrect Operating Frequency

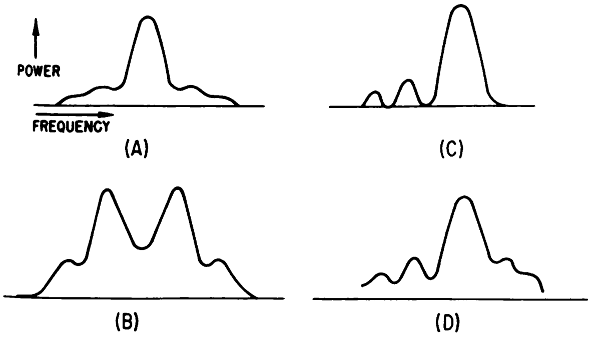
The trouble of incorrect operating frequency usually breaks down into two possible causes: (1) The magnetron may be defective; or (2) pulling may exist because of some fault in the RF system or from strong reflections from a nearby object.

When a new magnetron is inserted to correct off-frequency operation, it is not necessarily true that the original magnetron is defective. Individual constructional differences of magnetrons may vary, causing one to be pulled more easily by external conditions than another



AQ. 620

Figure 9-29.—Ideal spectrum of a pulsed magnetron.



AQ.621

Figure 9-30.—Magnetron spectral displays showing distortion.

of the same type number. It is seen, then, that irresponsible replacement of apparently defective magnetrons may result in the rejection of good tubes. It is first necessary to check for the presence of pulling, to determine whether the magnetron actually is at fault. This check is made by measuring the VSWR of the RF system, with the slotted line placed as close to the magnetron as possible, or by feeding the magnetron output into a dummy RF load and rechecking the frequency. When off-frequency operation occurs with a low VSWR, the indication is that the magnetron should be replaced, unless, of course, it is of the tunable type.

Poor Spectrum

As was previously discussed, spectrum analysis is of considerable importance in the maintenance of radar systems. The reason for a poor magnetron spectral display or graph may be: (1) magnetron pulling, (2) magnetron pushing, (3) defective magnet, or (4) defective magnetron.

Magnetron Pulling

The test for magnetron pulling may be made by means of VSWR measurements or by the use of a dummy antenna, as mentioned above. Magnetron pulling may cause frequency shift, but this may go unnoticed if the frequency is still within the operating band.

Magnetron Pushing

A poor spectral display or graph is frequently evidence of magnetron pushing, and this fault is the result of improper modulator operation. When the output pulse is of improper shape or amplitude, especially at lower power levels, excessive AM or FM may be present. The test applied to the modulator is made with the aid of a synchroscope and voltage divider. The voltage divider serves the purpose of reducing the modulator pulse to a usable amplitude. This amplitude is observed and multiplied by the appropriate factor. The pulse shape is observed and compared with available waveform charts. Under certain conditions, the magnetron may cause improper loading of the modulator, and thus introduce pulse distortion. The use of a dummy load for the modulator eliminates this condition. The modulator dummy load is a resistive impedance equal to the firing impedance of the magnetron; in most cases, a voltage divider is built into the test equipment to facilitate the measurement of pulse amplitude. This load replaces the magnetron during pulse measurements, and, therefore, helps to isolate trouble definitely to the modulator.

Defective Magnet

A poor spectral display or graph often indicates defects in the magnetron magnet. Low magnetic strength may result from careless handling. Improper mounting may cause the magnetic field to enter the magnetron at the wrong angle on magnetrons utilizing a separate magnet. Mounting difficulties are quickly found on inspection, and magnetic field strength may be checked by using a gaussmeter. Under some conditions, reversal of the magnet may improve the spectrum.

Defective Magnetron

A poor spectral display or graph may indicate defective magnetron. A weak magnet may cause the magnetron input to exceed rated values, if so, continued operation will result in a damaged unit. Missing lines in the spectral display are the result of magnetron arcing, and, if excessive, may completely destroy the shape of the spectrum. New magnetrons display moderate arcing until seasoning is completed, and, therefore, should be allowed a sufficient breaking-in period before the spectrum is analyzed. As mentioned previously, the end of the useful life of a magnetron is characterized by an increase in arcing and general instability. When the output power is low, it usually indicates a weak magnetron or a low modulator output. This uncertain condition may be resolved by testing the modulator output pulse; normal pulse indicates that the trouble is in the magnetron.

RECEIVER SENSITIVITY

The performance of a radar receiver is determined by several factors, most of which are evolved and established in the design engineering of the equipment. In the paragraphs to follow, only those which are concerned with maintenance are considered. The more important factors are receiver sensitivity (which includes noise figure determination and minimum discernible signal (MDS) measurement), TR recovery time, receiver recovery time, and receiver bandwidth.

Many radar receivers have circuits which are designed to serve a special function. Three of these special circuits commonly encountered are instantaneous automatic gain control (IAGC), sensitivity time control (STC), and fast time constant (FTC). These circuits may be found in combination or singly, depending upon the purpose of the radar. In the test methods and procedures described herein, the special functions should be disabled. The automatic frequency control (AFC) circuit may be permitted to operate during the receiver tests. A good check on the AFC is to make the tests specified for manual tuning, then switch to AFC. If the AFC circuit is normal, the signal indications will not change.

Inefficient range performance of a radar system can be caused by troubles in the radar receiver. This is due to the great number of adjustments and components associated with the receiver. Loss of receiver sensitivity has the same effect on range as a decrease of transmitter power. For example, a 6-db loss of receiver sensitivity shortens the effective range of a radar just as much as a 6-db loss in transmitter power. Such a drop in transmitter power is very evident in meter indications and, therefore, is easy to detect. On the other hand, a loss in receiver sensitivity, which can easily result from a slight misadjustment in the receiver, is very difficult to detect unless accurate measurements are made.

Figure 9-31 shows a comparison of radar system performance versus maximum range.

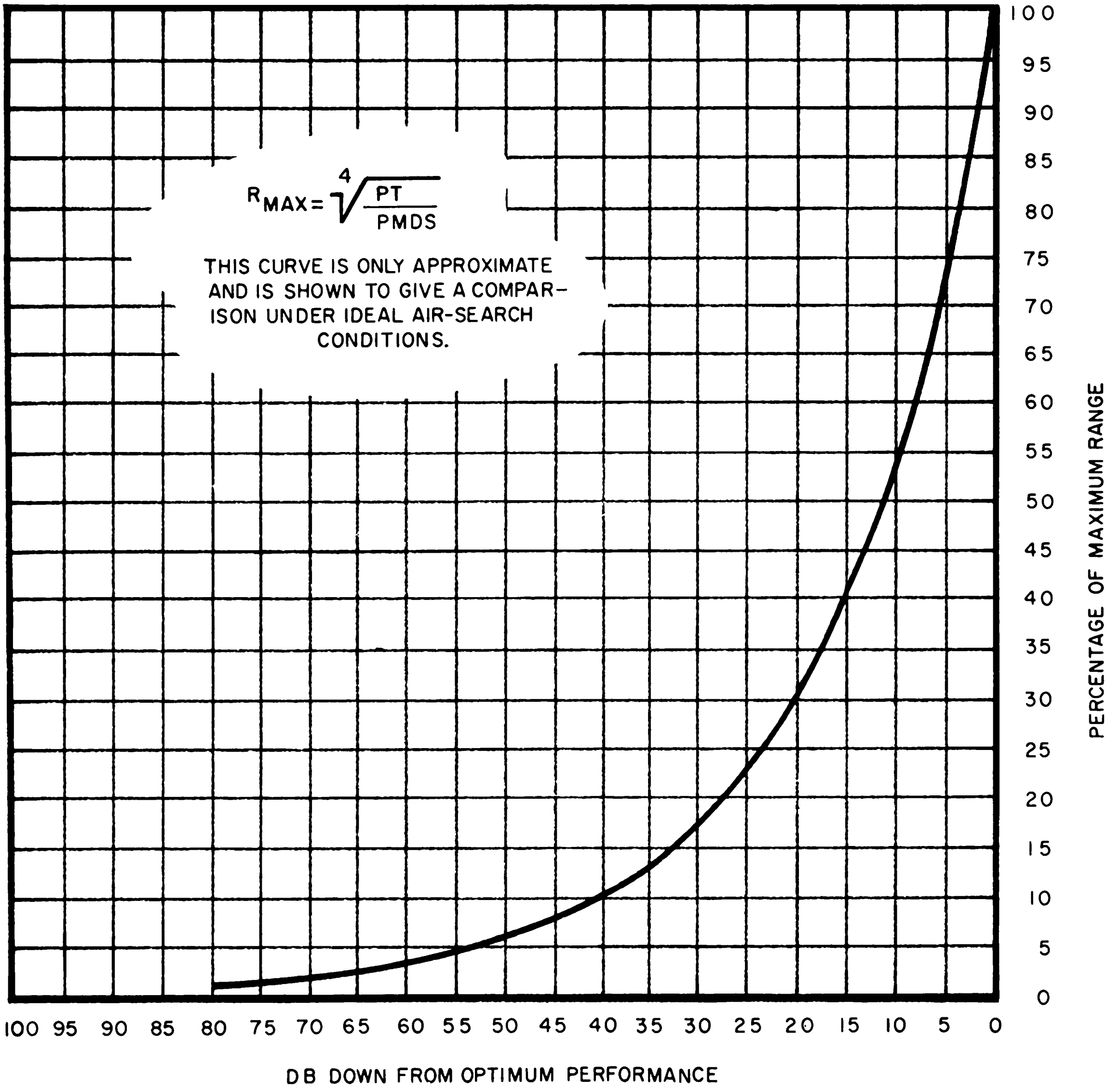


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Figure 9-31.—System performance versus maximum range.

The loss of system performance in db includes both transmitter and receiver losses. It should be noted that with a loss of 5-db in both receiver and transmitter (total of 10-db) performance, only 55 percent of the system's maximum range is realized.

The sensitivity of the receiver determines the ability of the radar to pick up weak signals. Greater sensitivity indicates that the receiver can pick up weaker signals. Sensitivity is measured by determining the power level of the MDS. MDS is defined as the weakest signal that produces a visible receiver output; its value is determined by the receiver output noise level which tends to obscure weak signals. It follows, therefore, that an MDS level is dependent upon eceiver noise level. (See Basic Electronics discussion on noise in amplifier circuits.)

e measurement of a minimum discernible l consists of measuring the power of a whose level is just sufficient to produce ible receiver output. If a radar receiver he specified MDS level, the noise figure d be correct also. Therefore, measure- of the MDS is a satisfactory substitute noise-figure determination, and is less licated. When readings are taken for com- on purposes, correct pulse length must be Maintenance instructions for the radar ill usually specify the pulse length to be in receiver sensitivity tests. In most cases l be the same as the transmitter pulse.

igure 5-12 (chapter 5) shows a simplified diagram of the AN/UPM-32 test set con- d for signal generator operation. When the set is operated as a signal generator, the et klystron oscillator supplies FM, pulse- lated, CW, or externally modulated micro- signals.

he klystron oscillator output passes through ncalibrated variable attenuator to a micro- tee. At this point the power splits evenly th directions. One-half goes to the power or for the reference level indication and her half passes through the calibrated vari- attenuator to the RF connection and the set. (It should be noted that tuning the ency meter to resonance will cause a dip power meter reading.)

he desired output signal is obtained by g the test set function selector switch to sition that provides the desired waveform e klystron oscillator reflector. Both the ency and power of the klystron oscillator ontrollable.

efore any measurements of receiver sen- ty can be made, the receiver must be ac- ely tuned to the radar-transmitter fre- y. To measure the receiver frequency, est set is connected to the radar set di- nal coupler. (Receiver frequency may be ured with the test antenna.) However to ccurate results, the sensitivity tests that ly follow frequency tests must be made the directional coupler.

ne the test set to the radar-transmitter ency as described in the Operation In- tion Manual for the test set. Upon check- if the receiver frequency is found to be ent than the previously measured trans- r frequency, the radar-receiver local oscillator is improperly adjusted or the transmitter frequency may have drifted.

There are two basic methods of measuring receiver sensitivity. One method is the pulse method where a pulse of measured amplitude and width is generated and coupled to the radar receiver. This method is rather difficult as consistent results require that the signal generator be tuned very accurately to the receiver frequency.

The second method employs a FM generator to sweep the signal generator across the receiver frequency. This method insures that the test signal is within the bandpass of the receiver. It also offers two main advantages over the pulse method; tuning the test set to the receiver frequency is not as critical, and receiver bandwidth tests can be made with relatively few changes in test set adjustments after sensitivity tests have been made.

Receiver bandwidth is defined as the frequency spread between the half-power points on the receiver response curve. Receiver bandwidth is specified for each radar, but wide variations are tolerated. If either the bandwidth or the shape of the receiver response curve is not within tolerances, a detailed check of circuit components may be necessary. Remember that a considerable change in the value of circuit components is required to alter the response materially. It is suggested that the receiver response be checked after any extensive repair to an IF amplifier.

Figure 9-32 shows a typical response curve of a radar receiver. The half-power points are shown as 3-db below maximum (midfrequency) response. Since the curve is plotted in terms of voltage, these points are also represented by the 70.7 percent voltage points ($\sqrt{1/2} = .707$) as shown in figure 9-32.

The time required to permit TR recovery is determined by the time it takes the TR switch to deionize after each transmitter pulse. It is usually defined as the time required for the receiver to return to within 6-db of normal sensitivity after the end of the transmitter pulse. However, some manufacturers use the time required for the sensitivity to return to within 3-db of normal or to full sensitivity. TR recovery time is the factor that limits the minimum range of a radar because the radar receiver is unable to receive signals until the TR switch is deionized. In various radar sets, the recovery time may vary from about 3 to 20 microseconds.

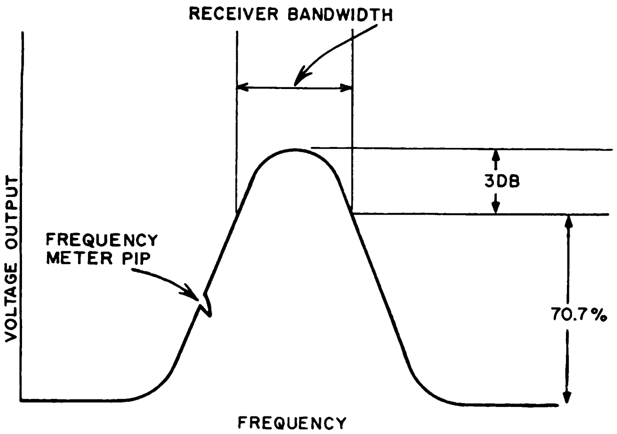

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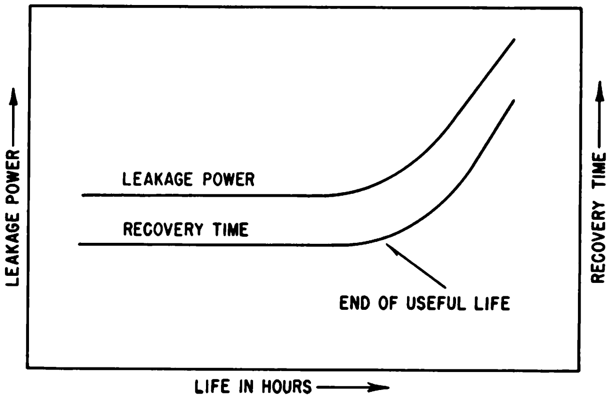
Figure 9-32.—Receiver response curve.



AQ. 630
Figure 9-33.—Graphic comparison of TR recovery time and leakage power.

The primary function of the TR section is to protect the crystal detector from the powerful transmitter pulse. Even the best TR switches allow some power to leak through; but when the switch is functioning properly, the leakage power is so small that it does not damage the crystal. It has been found, however, that the useful life of a TR tube is limited because the amount of leakage and the recovery time increases with use.

To insure efficient performance, some technicians make it a policy to replace the tube after a given number of hours of use. A better practice is to measure the TR recovery time at frequent intervals and make a graph or chart, which will immediately disclose any change in performance. Figure 9-33 shows how the recovery time is correlated with leakage power. Note that the end of the useful life of the TR tube is indicated by an increase in recovery time.

This method of checking the condition of a TR tube is reliable, because the recovery time increases before the leakage power becomes excessive. In practice, the TR tube is replaced when any sharp increase in recovery time becomes apparent. Ambient temperature has an effect on recovery time. The colder a TR tube, the greater is its recovery time. When tests are conducted under widely varying temperature conditions, this effect must be considered.

One method used in testing a TR tube is to measure the keep-alive current. This current maintains the TR tubes partial ionization to make the firing more reliable, and thus helps protect the crystal. The current is usually about 100 microamperes, and falls off as the end of the TR tube life approaches. Another method is to measure the keep-alive voltage between the plate and ground of the TR tube when the voltage source is known to have the correct output, and to record this voltage for use as reference for future checks. However, these checks are not as reliable as a recovery time test.

TR recovery time can be tested by means of a setup that utilizes a signal generator of either the FM or the pulsed type.

RECEIVER TROUBLES

Poor system performance may be caused by low receiver sensitivity (high MDS), poor AFC operation, and poor minimum range.

Low Receiver Sensitivity

Low receiver sensitivity is evidenced by a high MDS test figure. The reasons for this condition may be either excessive noise generation or excessive signal loss preceding the IF amplifier section. As long as the noise present in the receiver output is excessive, the IF amplifier cannot contribute to the sensitivity. When defective or improperly adjusted, the following items may cause low receiver sensitivity; crystal mixer, local oscillator, IF amplifier (first two IF stages), and the TR and ATR tubes.

Crystals may be tested most effectively under actual operating conditions. However, a series of crystal testers, of which the AIL Model 390 is representative, is available, and one of these testers may be used to correlate the d-c characteristics with circuit performance. Important crystal characteristics are conversion loss, noise figure, IF impedance, and RF impedance. These characteristics may be correlated with front-to-back resistance ratio and back current at 1 volt.

Poor AFC Operation

Because proper operation of the AFC circuit is primarily dependent upon coupling between the AFC crystal mixer, the local oscillator, and the output of the magnetron, this portion of the circuit should be checked first. A variable coupling is usually provided to adjust the amount of local-oscillator signal injection to the AFC crystal mixer. Care should be taken to prevent overloading of the AFC crystal mixer, and reference should be made to the applicable instruction book as to the correct crystal current for proper operation. Usually one milliampere of crystal current is the allowable limit. If the degree of coupling is found to be correct, the trouble may lie in a defective local-oscillator tube. The local-oscillator must operate smoothly over the desired pull-in frequency range if normal AFC operation is to take place. In addition, it is essential to make sure that the local oscillator is operating in the correct mode. A magnetron with an improper frequency spectrum may also cause the AFC circuit to seem defective.

Poor Minimum-Range Performance

Minimum-range performance is controlled by the recovery time of the TR tube (and, if used, the pre-TR tube). Excessively long recovery time, of course, indicates the end of the useful life of a TR tube.

CHAPTER 10

RADAR INDICATORS

The video-frequency signal from the output of the radar receiver is fed to the indicator unit. The indicator unit consists of an indicator scope and the electronic circuits that are necessary to present the desired information on the scope. Only the methods of presenting the desired information on the radarscope and the external operating controls for the radar indicator scope will be discussed.

The type of scope used by most radars is similar to the type used in fast-sweep test oscilloscopes. The radarscope uses a rapid linear sweep with sweep time measured in microseconds.

All cathode-ray tubes (CRT's) have a few common elements. There is an electron gun, or cathode, that produces a beam of electrons. The face of the tube is covered on the inside surface with a phosphor coating that emits light when excited by the electron beam. The walls of the tube are coated with a conducting material that is kept at a high potential with respect to the cathode. This conducting material acts as an anode and collects the electrons after they have excited the phosphor coating on the face of the scope. Most CRT's have one or more grids, as well, to regulate the electron beam in direction and intensity.

METHODS OF DEFLECTION

The basic difference between CRT's lies in the method by which the electron beam is deflected, or moved, across the face of the tube. There are two widely used methods of deflecting the electron beam. One is known as ELECTROSTATIC deflection and the other as ELECTROMAGNETIC deflection.

ELECTROSTATIC DEFLECTION

Most vacuum tubes have one common feature—a centralized cathode surrounded by various other elements. The electrons emitted from their cathodes are sent out radially in all directions. However, the electrons emitted from the cathode of a CRT are confined to a parallel beam by means of what is commonly called an electron gun.

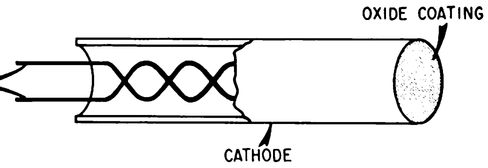
The electron gun consists of a cathode, a grid which concentrates the electrons into a beam, and anodes which focus the beam of electrons on the screen.

The cathode of a CRT is indirectly heated and consists of a small metal thimble inside of which the heating element or filament is mounted. To make the cathode a good emitter when heated, the front end is concave and oxide coated as shown in figure 10-1. It should be noted that emission is from the front end only.

The filament, which is made of tungsten wire, is wound in a double spiral so that the electron beam will not be affected by the applied a.c. In this way the magnetic field of each winding is canceled by the equal and opposite field of the other winding. The filament is electrically insulated from the cathode. However, the insulation does touch the cathode to provide good heat conduction.

The grid is essentially a metallic cylinder in the form of a cap which surrounds the cathode and has a small hole in the end. The potential applied to the grid is negative in respect to the cathode and, as a result, an electrostatic field is developed between the two as shown in figure 10-2.

An electron that starts out in the direction of KA is bent by the lines of force so that it takes the path KCP. In a similar fashion, the electron which starts out in the direction KB is bent so that it takes the path KDP. Thus the paths of these two electrons intersect at P, and all the electrons which pass through the hole in the grid are concentrated in this manner into a beam of electrons.



AQ.167
0-1.—Filament and cathode of a CRT.

lines of force between the grid and
prevent the emitted electrons from di-
from the cathode and cause them to
ard along the axis of the electron gun.
y even cause the electrons to cross
diverge on the opposite sides. The
the CRT also controls the number of
emitted by the cathode in a manner
o the action of a grid in a conventional
tube. Therefore, the grid of the CRT
two functions—(1) it controls the
of the cathode, and (2) it acts as a
ch concentrates the electrons into a

ntensity of the spot on the fluorescent
epends on the number of electrons in
. The number of these electrons, as
eviously, is controlled by the difference
e between the grid and cathode or grid
st CRT's utilize a potentiometer to
bias, thus enabling the operator to con-
brightness of the spot. This potenti-
ay be known by several different names
intensity, brilliance, or brightness

ition to the grid and cathode, the elec-
also contains two anodes. The con-
of the anodes is similar to that of
The first anode, sometimes called
ing anode, is closer to the grid and is
y a few hundred volts in respect to the
The second anode or accelerating anode
line and is at a much higher positive
than the first anode.

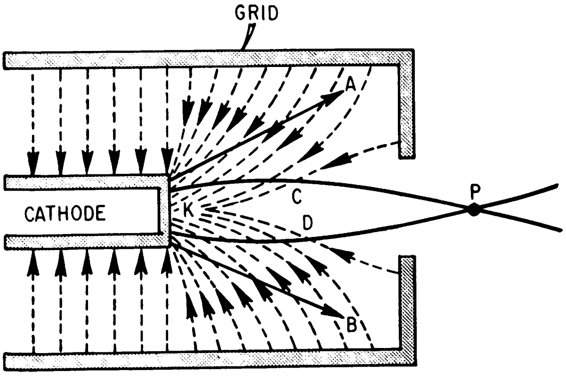
own in the previous illustration, the
beam is in focus at point P which is
the grid. However, the beam must
in focus when it strikes the screen.
ccomplished by the electrostatic field
he two anodes. (See fig. 10-3.)

ctron introduced into the field at point
tend to follow one of the lines of force
e more positive anode. Because of the
ge on the anodes, the electron travels at an extremely high velocity and does not remain in the field long enough to be pulled completely off its course. However, it is subjected to forces as it moves through the field. For example, an electron which is traveling from point P along the path PAB is curved toward the axis by the lines of force and thus takes the path PAC. In the center, the lines of force are nearly parallel to the axis and in the direction of point S. Therefore, the beam of electrons is accelerated in the direction of point S.

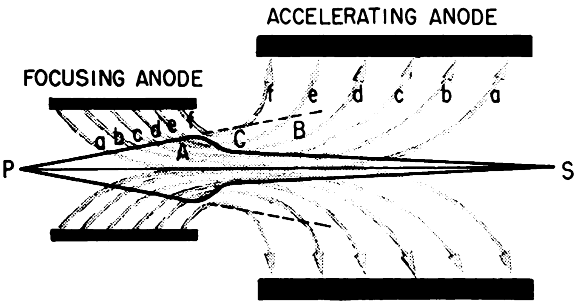
The point where the electrons converge may be shifted by varying the strength of the field between the two anodes. This is usually done by a potentiometer which varies the voltage on the first anode. This control is sometimes called the focus control.

The screen is made fluorescent by a coating of materials deposited on its inner surface. These materials, called phosphors, emit light when struck by a beam of rapidly moving electrons. The color and persistence of the light depend upon the composition of the particular phosphor used. Phosphors are designated by the letter P followed by a number which indicates its persistency. The higher the number, the longer the persistency. These numbers fall between 1 and 31 but bear no relationship to the time an image will persist on a screen. However, most airborne radar indicators use CRT's with long persistency.

CRT screens vary in size, color, and persistency. Manufacturers indicate the size by using the size in inches as the first digit in the tube's designation.



AQ.168
Figure 10-2.—Electrostatic field between grid and cathode.



AQ.169

Figure 10-3.—Electrostatic field between the first and second anode.

The electrons reaching the screen give up energy in producing luminescence. When this is accomplished, they must be removed or a large negative charge would develop on the screen. Thus, some method must be used to return the electrons to the power supply. Since the electrons striking the screen are traveling at a very high speed, they cause other electrons to be emitted (called secondary emission). The aquadag coating, which consists of a conductive material deposited on the flare of the CRT is connected to a very high voltage. (See fig. 10-4.) Many of the secondary emission electrons are attracted by this high potential. Thus, the electrons are returned to the power supply. The aquadag coating also serves as a shield for the electron beam.

The deflection plates are the final components necessary to complete the electrostatic CRT. There are two pairs of deflection plates which are set at right angles to each other, and the electron beam passes between all four of the plates. The plates are called vertical and horizontal deflection plates according to the direction in which they deflect the beam and not according to the manner in which they are mounted. Figure 10-4 illustrates the mounting of the deflection plates.

The amount of deflection caused by a set of deflection plates depends upon the velocity of the electron beam, the voltage applied between the plates, and the spacing of the plates. A measurement of this deflection is called deflection sensitivity. Deflection sensitivity is defined as the number of millimeters the spot on the screen will be deflected when one volt is applied to the deflection plates. Thus, a deflection sensitivity of 0.22/volt means that for each volt d.c. applied between the plates causes a deflection of 0.22 mm.

A more useful measurement of deflection is known as the deflection factor—measured in volts per millimeter or volts per inch. This factor indicates the voltage that must be applied between the plates to obtain a deflection of 1 mm or 1 inch. Tube manuals give the deflection factor in volts per inch.

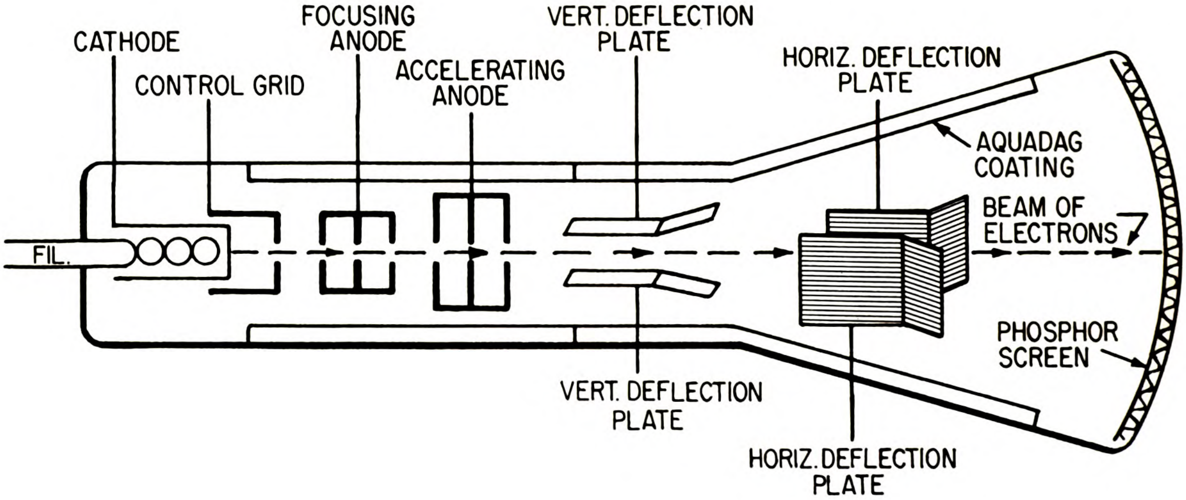
ELECTROMAGNETIC DEFLECTION

The electron gun of the electromagnetic CRT is very similar to the electron gun found in the electrostatic type of CRT. However, there are some differences in the two types which are primarily in the method of focusing and deflecting the electron beam. As the name implies, focusing and deflection are by an electromagnetic deflection. (NOTE: An electromagnetic CRT could employ electrostatic focusing.)

In this type CRT, the first anode (after the control grid) serves as the accelerating element rather than as the focusing device. The second anode (rather than being the accelerating anode as in the electrostatic CRT) is the aquadag coating with a high-positive potential applied to it. It serves the same purpose as aquadag coating in the electrostatic type CRT. However, it does aid in accelerating the electrons and may sometime be referred to as an accelerating anode.

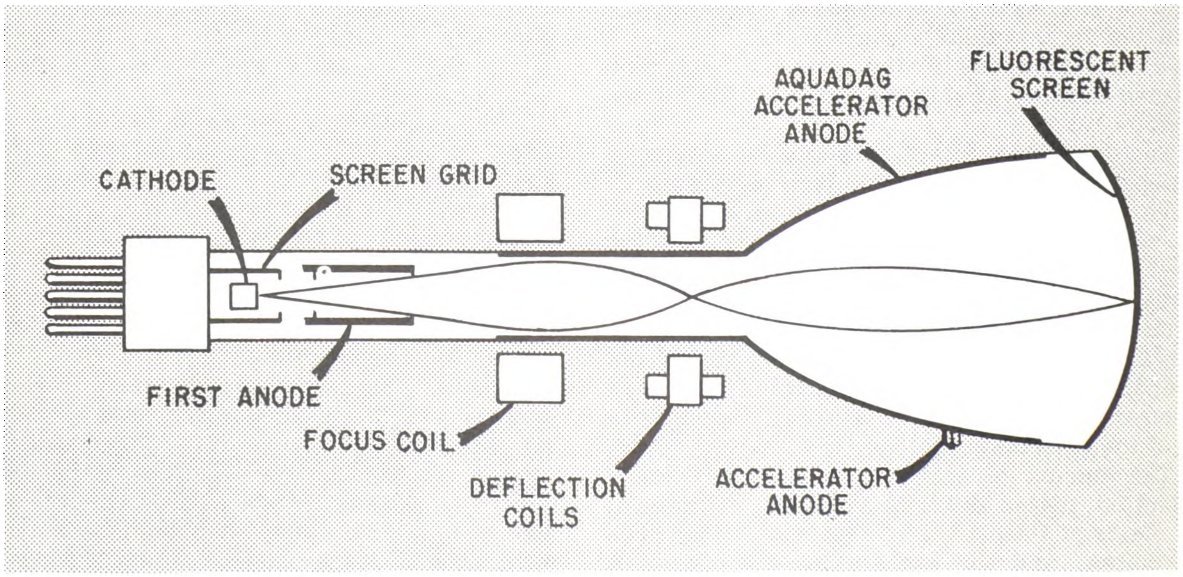
The focusing coil of the electromagnetic CRT replaces the second anode and performs the same function as the first anode in the electrostatic CRT. The deflection coils, or deflection yoke as it is sometimes called, replaces and performs the same function as the deflection plates in the electrostatic type CRT. Figure 10-5 is an illustration of the complete basic electromagnetic CRT.

The focusing coil is essentially an electromagnet which fits around the neck of the CRT as illustrated in figure 10-6. When a d-c current flows through the windings of the coil, a magnetic field is set up, part of which is within the neck of the tube. It should be noted that within the neck the magnetic lines of force have a mean direction which is along the axis of the neck. Thus, the magnetic field causes the electron beam to converge. The amount of current



AQ.170

Figure 10-4.—Electrostatic CRT.



AQ.171

Figure 10-5.—Electromagnetic CRT.

in the coil may be controlled by a rheostat (focus control), thus controlling the strength of the magnetic field.

The manner in which the electron beam is focused may be explained with the aid of figure 10-6. Point P is the crossover point which the electron beam is assumed to have reached after being emitted by the cathode, acted upon by the grid, and accelerated by the first anode.

The electrons traveling down the axis of the tube will not be affected by the magnetic field. Those electrons traveling at a small angle will have a force applied to them perpendicular to the magnetic field. This force will tend to bring the electrons back into the line of travel. This action, however, could cause the electrons to oscillate back and forth across the neck of the tube and gradually damp out. As shown in figure 10-6, an electron traveling along the line PAB or PDE would be forced by the magnetic field to take the paths PACS and PDFS, respectively. All electrons coming from the crossover point P and entering the magnetic field follow paths that make them meet at the common point S.

However, it is possible that an electron could be traveling off to one side or the other as well as at an up or down angle. Thus, the magnetic field could be acting on the electrons in more than one direction at one time, which would effectively result in a spiral path of travel by the electrons, as illustrated in figure 10-7. If you could look down on the face of the scope and see the paths of the electrons you would see spirals such as these. Spiral (A) is the path of an electron that entered the magnetic field at a greater angle than in spiral (B). However, it travels faster and they both reach point S at the same time. In order to focus the beam, it is only necessary to adjust the strength of the magnetic field so that the common point S falls on the fluorescent screen.

Although we have considered using only electromagnets for focusing, a permanent magnet can perform the function equally as well. Some CRT indicators utilize permanent magnet focusing devices. The permanent magnet encircles the neck of the CRT in a manner similar to the focusing coil. Focusing of the electron beam is accomplished by moving the magnet along the axis of the tube until the beam of electrons is sufficiently concentrated at the face. Another means of adjusting the focus of an electron beam with a permanent magnet would require the use of a shunt. The shunt would be adjusted to increase or decrease the concentration of magnetic flux in the neck of the CRT.

Electromagnetic deflection is sometimes more desirable and offers some advantages over electrostatic deflection. One big advantage is that tube construction is simpler since there

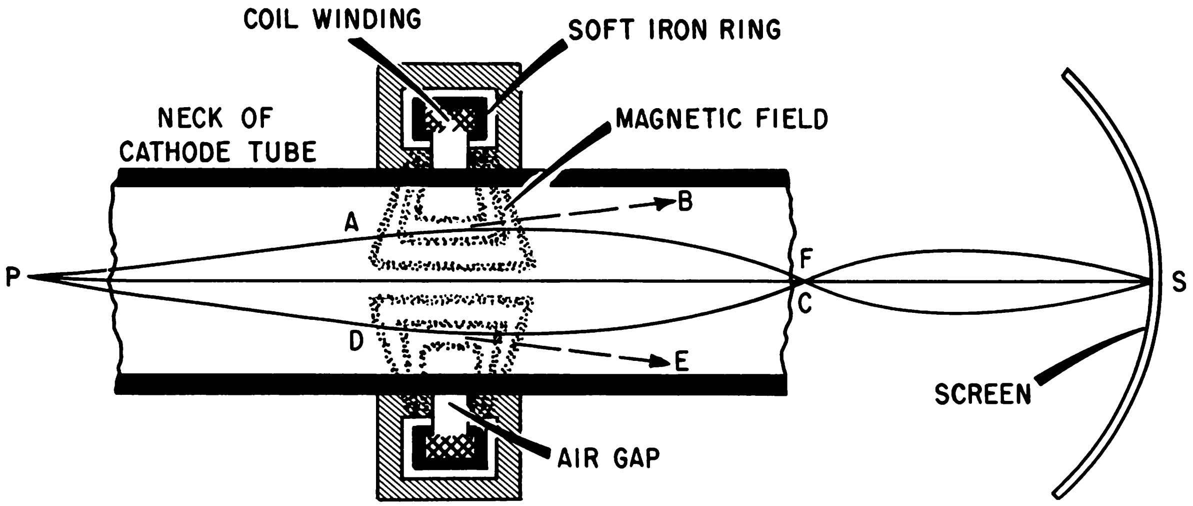


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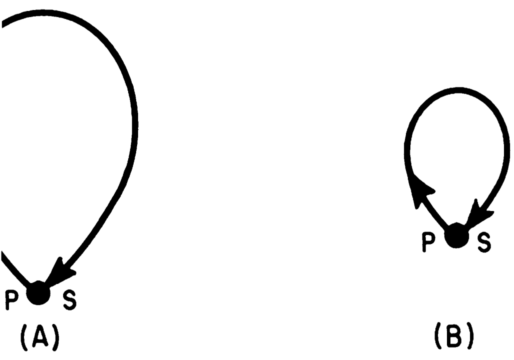
Figure 10-6.—Electromagnetic focusing.



AQ.173

Figure 10-7.—End view of the paths of the electrons.

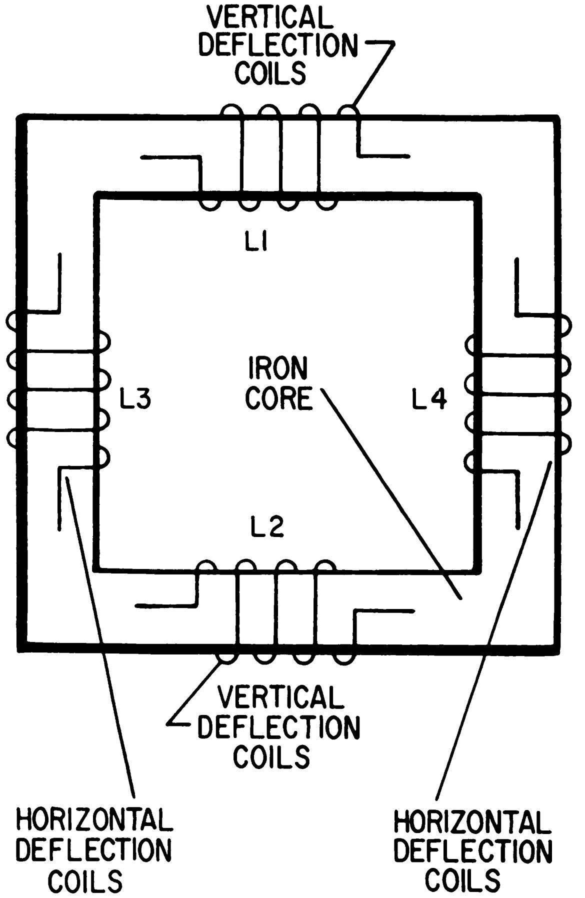
o deflection plates within the tube. Another tage is that high amplitude deflection volt- are not required since it is a current ted device.

o understand electromagnetic deflection of ectron beam in a CRT, it is essential that viation Electronics Technician understand roperties and characteristics of current ing conductors, their magnetic fields, he interaction between two or more mag- fields.

he electromagnetic deflection method most nonly used employs the stationary deflec- yoke. A schematic of the yoke is shown in e 10-8.

s illustrated, the deflection yoke consists ly of an iron core and two sets of deflec- coils mounted at right angles to each other. set provides vertical deflection of the elec- beam and the other horizontal deflection. coil is composed of many turns of wire, he coils of each set are connected so that nagnetic fields set up by each pair of coils l in the same direction and parallel across eck of the CRT.

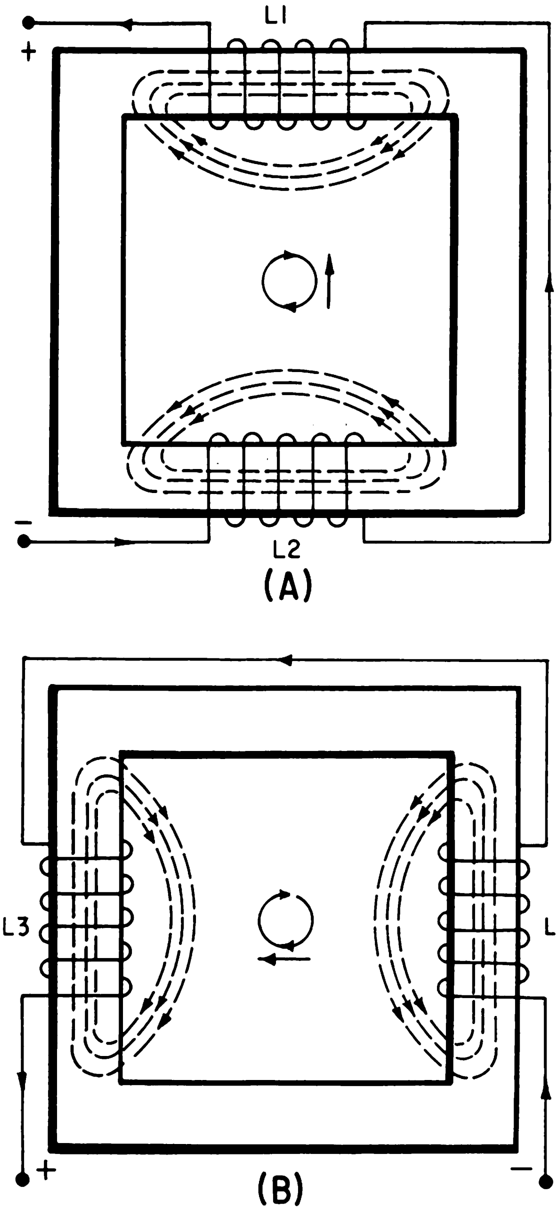
he two coils of each set are wound in series sition to each other on the iron core. Thus, the flux produced by each is in opposi- within the iron core), the only way in which ines of force can form closed loops is by sing the neck of the CRT. By using two sets oils in this manner, two magnetic fields e set up across the neck of the CRT which are at right angles to each other. Figure 10-9 is an illustration of the two sets of deflection coils and their respective magnetic fields.


VERTICAL DEFLECTION COILS
L1
IRON CORE
L3
L4
L2
VERTICAL DEFLECTION COILS
HORIZONTAL DEFLECTION COILS
HORIZONTAL DEFLECTION COILS

AQ.174

Figure 10-8.—Basic illustration of a stationary deflection yoke.

In both (A) and (B) of figure 10-9, it should be noted that the electron beam is coming out of the paper. Thus, the magnetic field around the beam is moving clockwise. As shown in (A) of figure 10-9, the magnetic flux set up by L_1 covers the upper half of the tube's neck and is in opposition to the flux around the electron beam. The magnetic flux covering the lower half of the tube's neck is established by the current flowing through L_2 and is traveling in the same direction as the lines of force around the electron beam; thus they are aiding or



AQ.175

Figure 10-9.—(A) Vertical deflection; (B) horizontal deflection.

reinforcing the flux in the lower half. The flux's resultant force on the electron beam is in an upward direction; thus, the beam will be deflected in an upward direction. Therefore, it can be seen that an electron moving perpendicular to a magnetic field is deflected at right angles to its path and to the field.

If the direction of current flow through the windings L_1 and L_2 is reversed, the direction of the flux set up by each will also be in the opposite direction. With the magnetic flux around the beam unchanged, the resultant force acting on the electron beam will also be in the opposite direction. Therefore, the electron beam will be deflected in a downward direction.

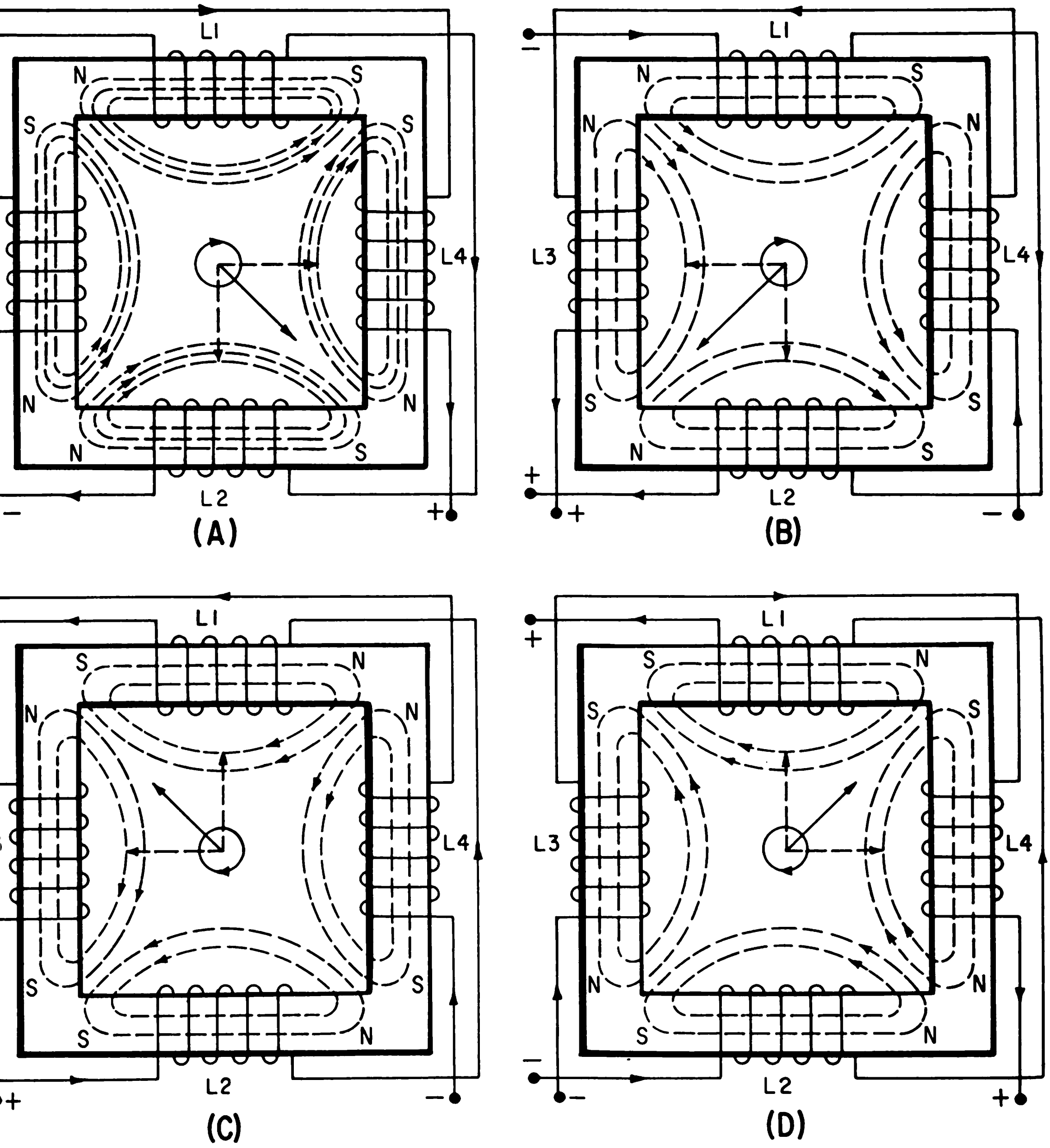
The speed at which the electron beam will be deflected across the screen of the CRT will be dependent upon the rate of change of current flow in the windings. The maximum distance that the electron beam will be deflected will be dependent upon the amount of magnetic flux established by the coils.

Part (B) of figure 10-9 is an illustration of a set of coils similar to the coils illustrated in part (A) except that they are oriented to deflect the beam in the horizontal plane. Deflection of the electron beam is accomplished by coils L_3 and L_4 in a manner similar to the deflection in the vertical plane by coils L_1 and L_2. As illustrated, the electron beam is deflected to the left; but if the current through the coils is reversed in direction, the beam will be deflected in the opposite direction across the screen of the CRT.

Thus far the vertical and horizontal deflection coils have been discussed separately. However, if they were wound on the same iron core and energized simultaneously, the electron beam could be deflected in directions other than in the vertical and horizontal plane. The operation of the stationary electromagnetic yoke is based on this principle.

Figure 10-10 is used to further illustrate the operation of the deflection coils and how the electron beam can be deflected in various directions. The electron beam is coming out of the paper and the amplitude of the current through each coil is the same for each illustration in figure 10-10.

When current flow through L1, L_2, L_3, and L_4 is as shown in figure 10-10 (A), the beam will be deflected in the direction indicated. The direction of the movement is the result of the vertical and horizontal forces acting on the electron beam which are illustrated by broken lines. Since each of the forces is equal, the resultant force is 45° from or halfway between the two.



AQ.176

Figure 10-10.—Deflection yoke.

rrent continues to flow in the same in L_1 and L_2 but is reversed in the al coils L_3 and L_4, the effect will be in (B) of figure 10-10.

With the current continuing to flow in the same direction through L_3 and L_4 but reversed in L_1 and L_2, the deflection of the electron beam will be in the direction as illustrated in (C) of figure 10-10. Reversing the current through L3 and L4 again, but leaving L1 and L2 unchanged, will cause the electron beam deflection to advance another 90° around the screen of the CRT. (See fig. 10-10 (D).)

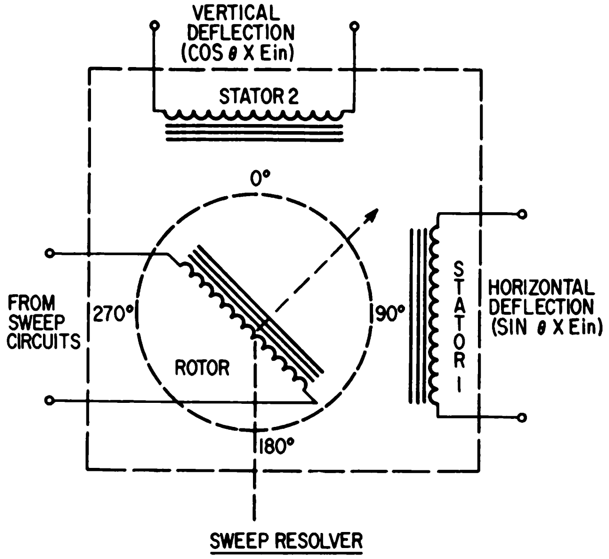
In summary, it should be recalled that current flow in the vertical deflection coils produced either an upward or downward deflection of the electron beam, depending on the direction of current flow. The same was true of the left or right deflection produced by current in the horizontal deflection coils. When the current flow through the two sets of deflection coils was equal, the deflection of the electron beam was 45° from the vertical and horizontal planes. However, the quadrant in which the beam was deflected depended on the direction of current flow through the coils and not the amplitude.

It should be noted that as the current in each set of coils was reversed consecutively, one after the other, the trace produced by the electron beam advanced around the screen of the CRT by an angular amount of 90°. However, to have one type of scope presentation (a PPI-type scan), the trace on the screen must appear to be continuously rotating about the center axis of the CRT. This can be accomplished by varying the amplitude of the deflection currents applied to each set of deflection coils at a sine-wave rate, but the amplitude variations in one pair of coils must be 90° out of phase with those in the other pair.

The synchro resolver, sometimes called a sweep resolver, is normally used in airborne radar equipment to provide currents of the proper value and relationship to produce a rotating sweep.

Figure 10-11 is a schematic of a sweep resolver, the rotor of which is positioned in synchronism with the antenna. The sweep voltage from the sweep generator located in the synchronizer is applied to the rotor winding. The output amplitude and polarity from each of the stator windings will depend upon the relative position of the rotor. The current outputs from the stator windings of the resolver are applied to the deflection coils of a CRT.

If the antenna is pointing dead ahead at 0 degrees azimuth, the vertical deflection of the electron beam must be maximum upward and the azimuth deflection, zero. At 90° or 270° azimuth, the vertical deflection must be zero and the horizontal deflection maximum either left or right. Thus, the outputs of the stators are:


VERTICAL DEFLECTION (COS θ X Ein)
STATOR 2
0°
FROM SWEEP CIRCUITS
270°
ROTOR
90°
STATOR I
HORIZONTAL DEFLECTION (SIN θ X Ein)
180°
SWEEP RESOLVER

AQ.177

Figure 10-11.—Sweep resolver.

Stator 1 (to horizontal deflection coils) = $E_{in} \times \sin \theta$

Stator 2 (to vertical deflection coils) = $E_{in} \times \cos \theta$

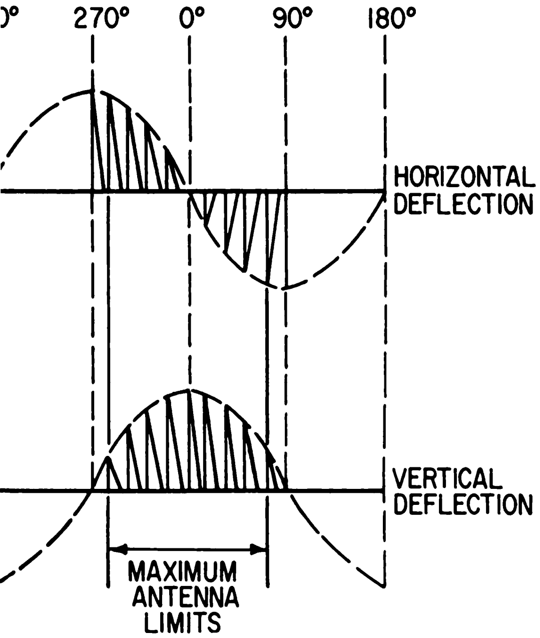
where θ is the antenna position.

Figure 10-12 is an illustration of the outputs from the two stator windings with the antenna rotating back and forth in azimuth between the limits indicated. It should be noted that the outputs vary at a sine wave rate 90° out of phase.

TYPES OF SCANS

The discussion of the various types of CRT's thus far has been limited to construction and operating principles. However, before the CRT can be of value in airborne radar equipment, it must be capable of presenting data to the operator.

The pattern that is produced by the scanning of the electron beam over the face of the CRT determines the type of scan or presentation. The basic terms to be used are defined below.



AQ.178

Figure 10-12.—Resolver outputs.

\ sweep is the trace produced on the screen he CRT by the linear deflection of the elec- beam. The movement of the sweep across round the screen of a CRT is called scanning. s movement may also be synchronized with movement of the antenna which is also said e scanning a certain area of space.

There are several types of scans employed. y are usually designated by letter. The four c types are A-scan, B-scan, C-scan, and -scan. The principles of operation of the can, B-scan, and C-scan are discussed in ic Electronics, NavPers, 10087-C. Review he basic principles before continuing with present discussion is recommended.

-SCAN

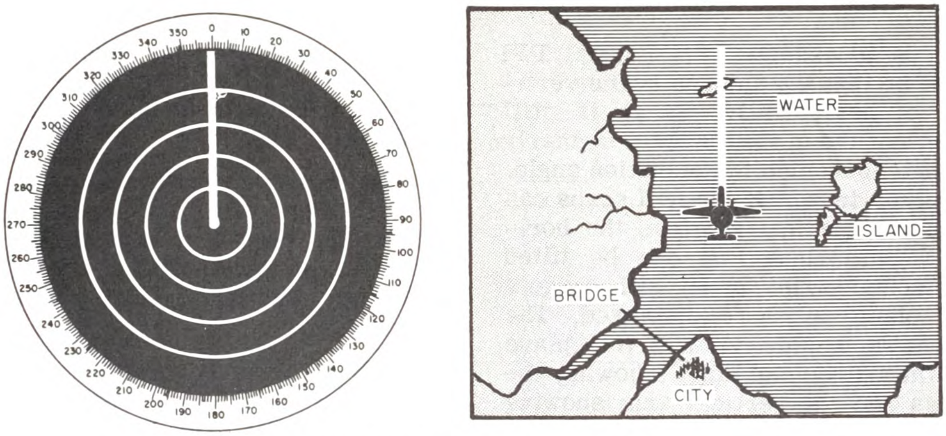
The term PPI may be interpreted to mean position indicator. The PPI-scan is another of scan developed for the purpose of pre- ing range and bearing information. It may considered as a modified type of B-scan in h the rectangular coordinates are replaced polar coordinates, thus presenting a polar like presentation of the area searched. Electromagnetic deflection is employed where a PPI-scan presentation is used. (See fig. 10-13.)

The antenna for the PPI-scan presentation is rotated uniformly about the vertical axis, thus, searching or covering an area in the horizontal plane. The beam radiated by the antenna is usually narrow in azimuth and broad in elevation to give great slant range covered during surface and air search. However, where this type of presentation is used, the antenna can rotate through 360° or scan a pie-shape sector ahead of the aircraft. The antenna may be caused to scan back and forth through a selected sector by use of controls available to the operator. The scanning rate is quite rapid; therefore, the area scanned is covered frequently and the observed targets are presented distinctly on the screen of the CRT.

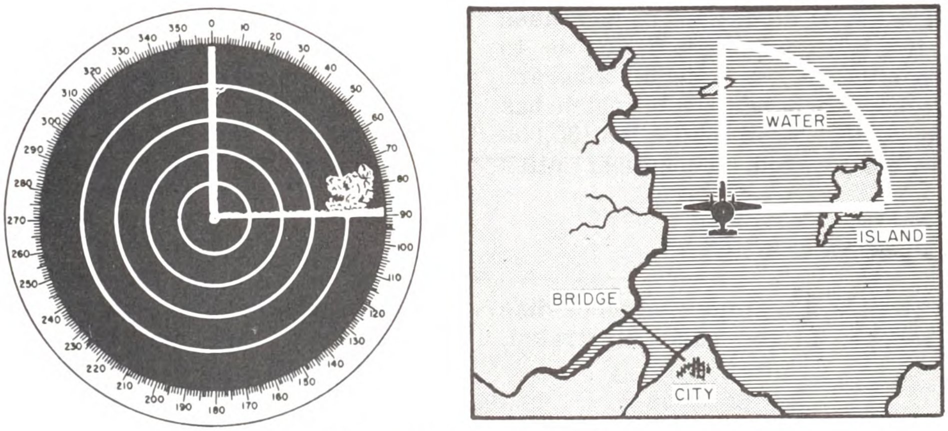
The PPI-scan is developed by causing the sweep or trace on the screen to rotate in synchronism with the antenna about the center axis of the CRT. Thus, each sweep is an indication of the instantaneous position of the antenna in azimuth. The rotation of the sweep is accomplished by varying the amplitude of the current through the vertical and horizontal deflection coils of the deflection yoke. The radial sweep is the time base and the range of a target is measured from the center of the screen (or from the sweep's starting point if depressed center is used) outward along the trace or sweep. Most PPI-scans utilize range markers to calibrate the screen. This is done by the timing system which causes the trace to be intensified at specific intervals. Thus, equally spaced concentric circles or arcs are produced which calibrate the screen in multiples of 1, 5, 10, or 20 miles or any other markers that are available for selection.

When a target echo is received, the intensity of the sweep increases, indicating the position of the target. The target may be presented in some detail, giving an indication of its size and shape. The target's range and relative position may be read directly from the screen with the aid of the range markers and an azimuth scale around the screen of the CRT.

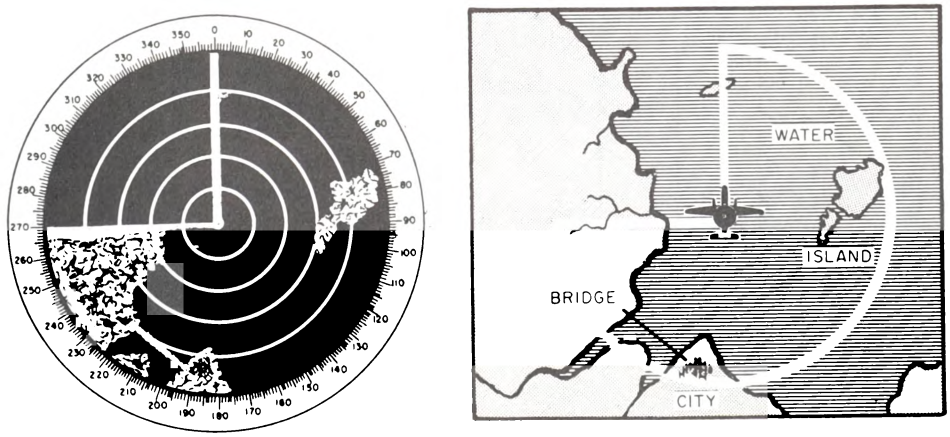
The indicators employed in airborne radar may vary considerably in construction, types of scans, and in operating principles. However, their operation may be reduced to one or more of the basic types of scans previously discussed.



ANTENNA POINTING DIRECTLY AHEAD (0°)



ANTENNA POINTING TO 90°



ANTENNA POINTING TO 270°

AQ.465

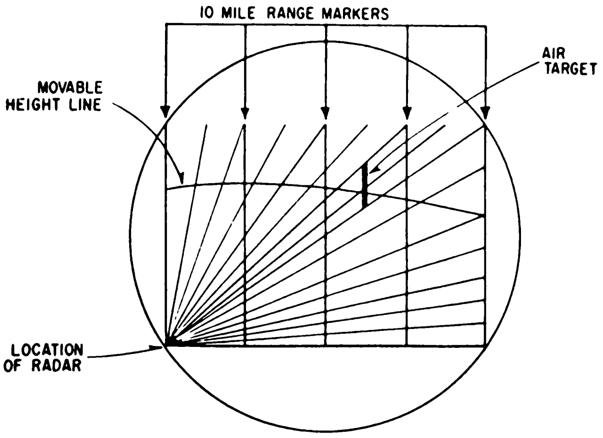
Figure 10-13.—PPI presentation.

RHI-SCAN

An RHI-scope is essentially a normal PPI laid on its side so that the antenna scans vertically instead of horizontally. Range is still shown radially, but the angle that was formerly the bearing angle becomes the elevation angle. The vertical plane in which the RHI scans can be rotated about a vertical axis, as the horizontal plane of a normal PPI can be tilted around a horizontal axis. In an RHI, targets in a vertical plane only are displayed. The RHI screen shows a side view of this plane (fig. 10-14), the horizontal axis showing the range in miles and the vertical axis showing directly the height of the target aircraft in feet, and not the elevation angle. Height instead of elevation angle is obtained by electronically combining the range with the sine of the elevation angle. The height scale must be increased or stretched if significant information is to be obtained, particularly for distant aircraft. Figure 10-14 shows a height scale which has been stretched so that 5 nautical miles (30,000 feet) is equivalent to about 20 nautical miles of range.

PPI-SCAN CIRCUITRY

Figure 10-15 shows a simplified block diagram of PPI-scope. In the case illustrated, the CRT has a fixed deflection yoke. The sawtooth sweep currents required to produce the rotating radial sweep line are obtained from the trapezoidal-voltage sweep generator, a rotary transformer (synchro resolver), and two push-pull amplifiers.



AT.521

Figure 10-14.—RHI-scan presentation.

The rotary transformer is a variable-ratio transformer with one primary winding (the rotor) and two secondary windings (the stator). The voltage ratio between the primary winding and each secondary winding changes when the rotor is turned.

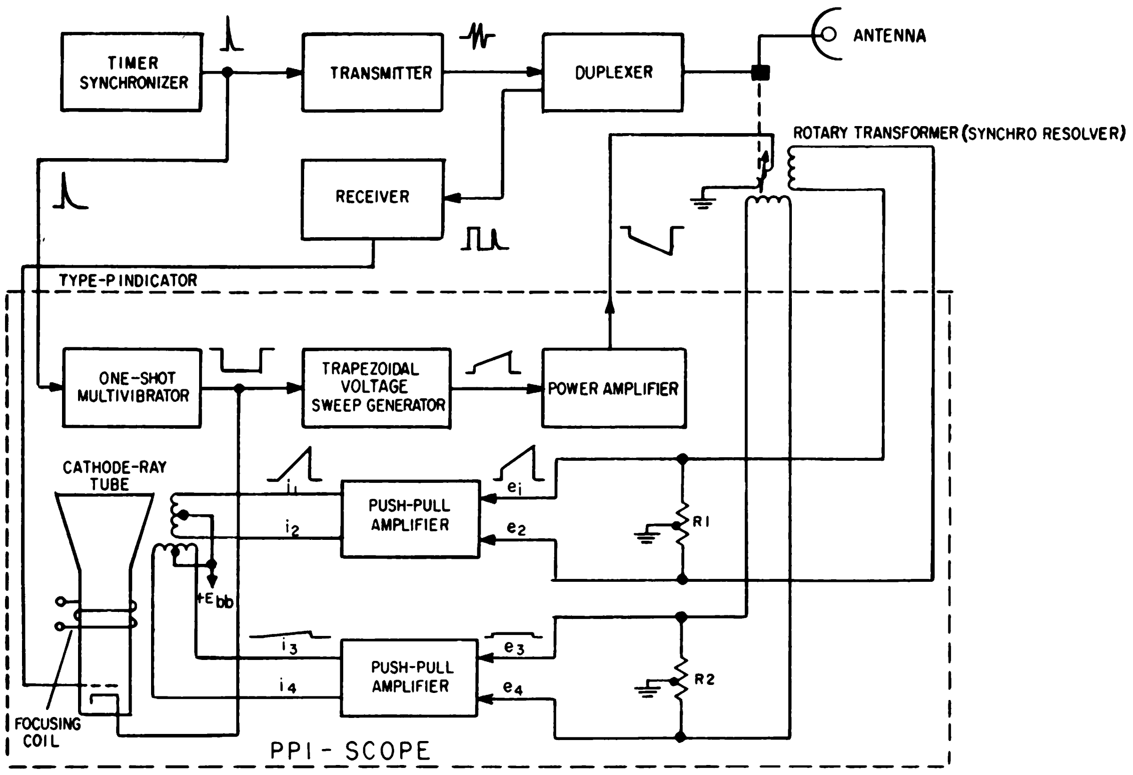
The rotor is connected mechanically to the radar antenna. Thus, when the antenna turns, the rotor turns, and the voltage ratio changes. One secondary voltage varies as the sine of the angle of antenna rotation; the other secondary voltage varies as the cosine of the angle of antenna rotation.

The plan position indicator operates as follows: Trigger pulses from the timer (synchronizer) are fed to both the transmitter and the one-shot monostable multivibrator. The one-shot multivibrator generates negative gate pulses that are applied to the trapezoidal-voltage sweep generator and the cathode of the CRT.

The output of the trapezoidal-voltage sweep generator is fed to a power amplifier. The output of the power amplifier is applied to the primary of the rotary transformer. The secondary voltages of the rotary transformer are trapezoidal and have amplitudes that depend on the antenna position.

To apply trapezoidal voltages to the two push-pull amplifiers, a center-tapped resistance network is connected across each of the two secondary windings of the rotary transformer. Network R1 produces two voltages (e_1 and e_2) of equal amplitude and opposite polarity, which are applied to one push-pull amplifier. Likewise, network R2 produces two voltages (e_3 and e_4) of equal amplitude and opposite polarity, which are applied to the other push-pull amplifier. For simplicity, only the waveforms of e_1 and e_3 are shown in figure 10-15.

Trapezoidal voltages e_1 and e_2 produce sawtooth sweep currents i_1 and i_2, respectively. Trapezoidal voltages e_3 and e_4 produce sawtooth sweep currents i_3 and i_4, respectively. The angular position of the radial sweep line at any instant depends on the relative amplitudes and the phase relationship of the sawtooth sweep currents at that instant.



AQ.466

Figure 10-15.—Block diagram of a PPI-scope system.

Sawtooth sweep currents i_1 and i_2 are equal in amplitude, but opposite in polarity. Likewise, i_3 and i_4 are equal in amplitude, but opposite in polarity. For simplicity, only the waveforms of i_1 and i_3 are shown in figure 10-15. The relative amplitudes and polarities of i_1 and i_3 (also of i_2 and i_4) vary as the rotary transformer is rotated. This causes the radial sweep line to rotate in synchronism with the radar antenna (which is geared to the rotary transformer).

In general, plan position indicators used in conjunction with rotary transformers also use clamping circuits (clampers). The clamping circuits insure that the scanning spot always starts from the same point on the PPI screen.

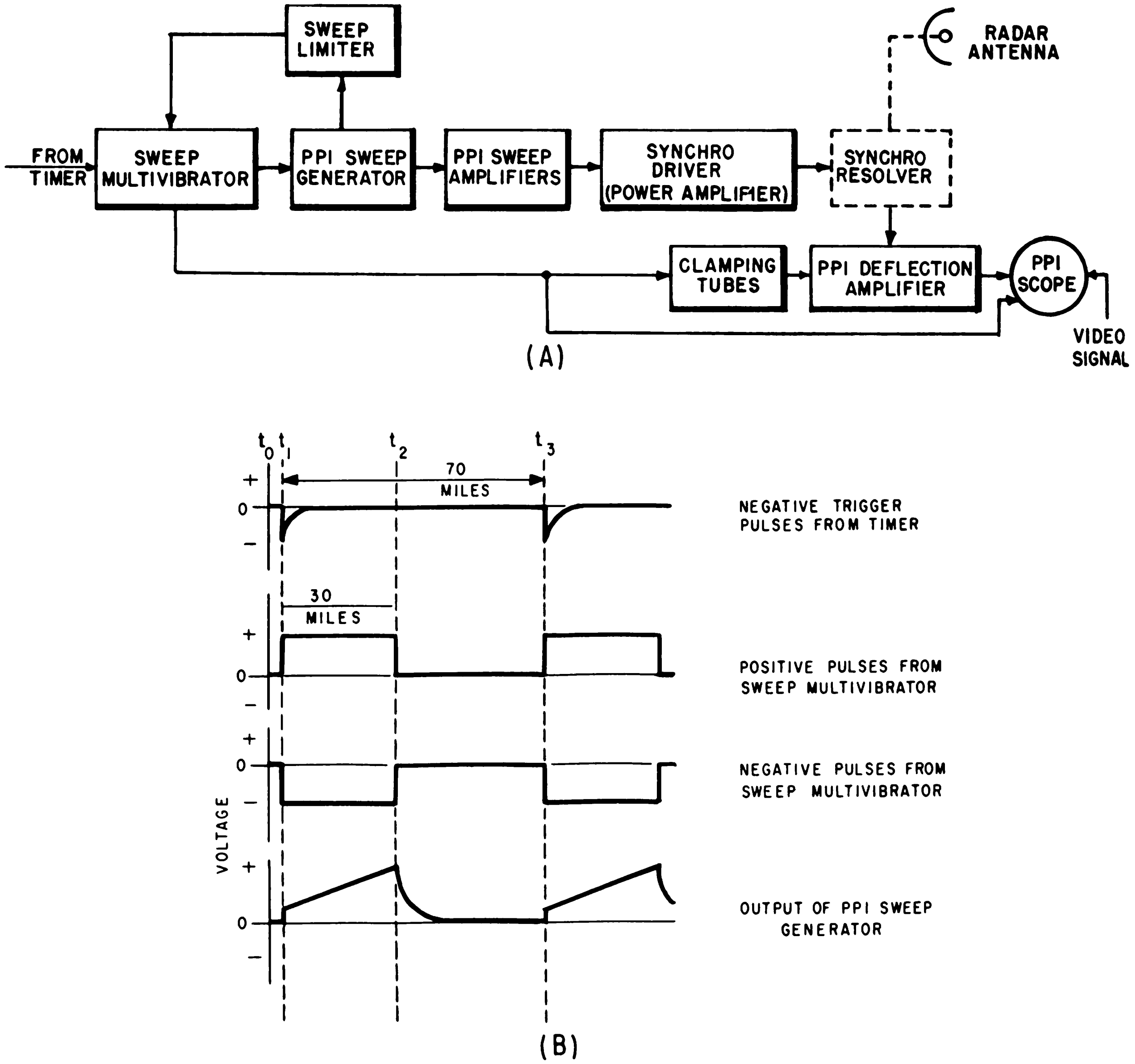
Negative gate pulses are applied to the cathode of the PPI CRT to intensify the electron beam during each sweep period. The electron beam is intensified to the point where the radial sweep line is barely visible. When echo signals are applied to the control grid of the CRT during each sweep period, the brightness of portions of the radial sweep line is increased.

SWEEP SYSTEM

The various types of deflection and sweep circuitry required for a simplified radar indicator system are shown in figure 10-16. Also shown are the waveforms for this indicator system when set for a 30-mile range sweep.

Negative trigger pulses from the timer are applied to the sweep multivibrator. When a negative trigger pulse is applied to it, the sweep multivibrator causes a switching action which initiates the sweep voltage in the PPI sweep generator.

When the sweep voltage reaches a predetermined level, the sweep-limiter tube conducts,



AQ.467

Figure 10-16.—(A) Simplified indicator, block diagram; (B) waveforms for a 30-mile sweep.

and causes a second switching action. As a result, the sweep multivibrator produces positive and negative rectangular pulses. The PPI sweep generator, on the other hand, produces a trapezoidal voltage.

The trapezoidal voltage is amplified by the PPI sweep amplifiers, and then applied to the synchro driver (power amplifier). The output of the synchro driver is applied to the rotor of a synchro resolver.

The synchro resolver has two stator windings and one rotor winding. The rotor shaft is mechanically coupled to the radar antenna. When the antenna rotates, the synchro-resolver rotor turns, and trapezoidal-sweep voltages of varying amplitude are induced in the synchro-resolver stator windings. The amplitude of the induced sweep voltages, at any instant, depends on the angular position of the rotor winding with respect to the stator windings of the synchro resolver.

The induced sweep voltages are amplified by the PPI deflection amplifiers, and then applied to the deflection coils of the PPI-scope. As a result, a radial sweep line is produced on the PPI screen. Because of the mechanical coupling between the radar antenna and the synchro-resolver shaft, the radial sweep rotates in synchronism with the antenna.

The negative rectangular pulses from the sweep multivibrator are applied to the clamping tubes and the CRT of the PPI-scope. The clamping tubes insure that the PPI electron beam always starts its sweep trace from the same point on the PPI screen.

The negative rectangular pulses applied to the CRT intensify the scope electron beams during the sweep time. This produces a faintly visible trace on the scope.

Indicator blanking during nonsweep time is accomplished by the use of an intensity gate circuit. This is discussed in chapter 16 of this course.

Radial Sweep Line

The radial sweep line on the screen of a plan position indicator is obtained by sweeping the electron beam from the center to the edge of the PPI screen. To obtain azimuth (bearing) indication, the radial sweep line is rotated about the center of the screen, like a spoke of a wheel.

When a sawtooth sweep current is applied to the deflection coil, as shown in figure 10-17, a magnetic field is produced. The magnetic field causes the electron beam to be deflected, thereby producing a radial sweep line. The amount of beam deflection and, consequently, the length of the radial sweep line depend on the amplitude of the sawtooth sweep current.

The direction of beam deflection, and consequently, the position of the radial sweep line, is always perpendicular to the magnetic field. This system uses a fixed deflection yoke with horizontal and vertical deflection coils. Sawtooth sweep currents are applied simultaneously to the two deflection coils. The direction of the radial sweep line obtained depends on the relative amplitudes of the two sweep currents. To insure that the deflection caused by the sawtooth is in one direction (fig. 10-18 (A)), the base of the sawtooth must be at zero potential. To position the base of the sawtooth at zero volts, another waveform must be combined with the sawtooth. If the negative portion of a square wave is added to the end of the sawtooth, and if the area of the negative portion of the square wave is equal to the area of the sawtooth, the average of the waveform will be at the base of the sawtooth. (See fig. 10-18 (B).) The current in the deflection coils caused by the sawtooth

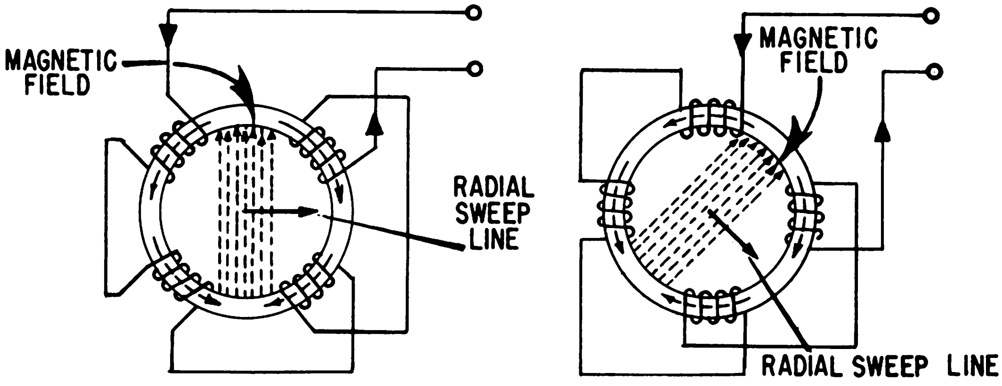


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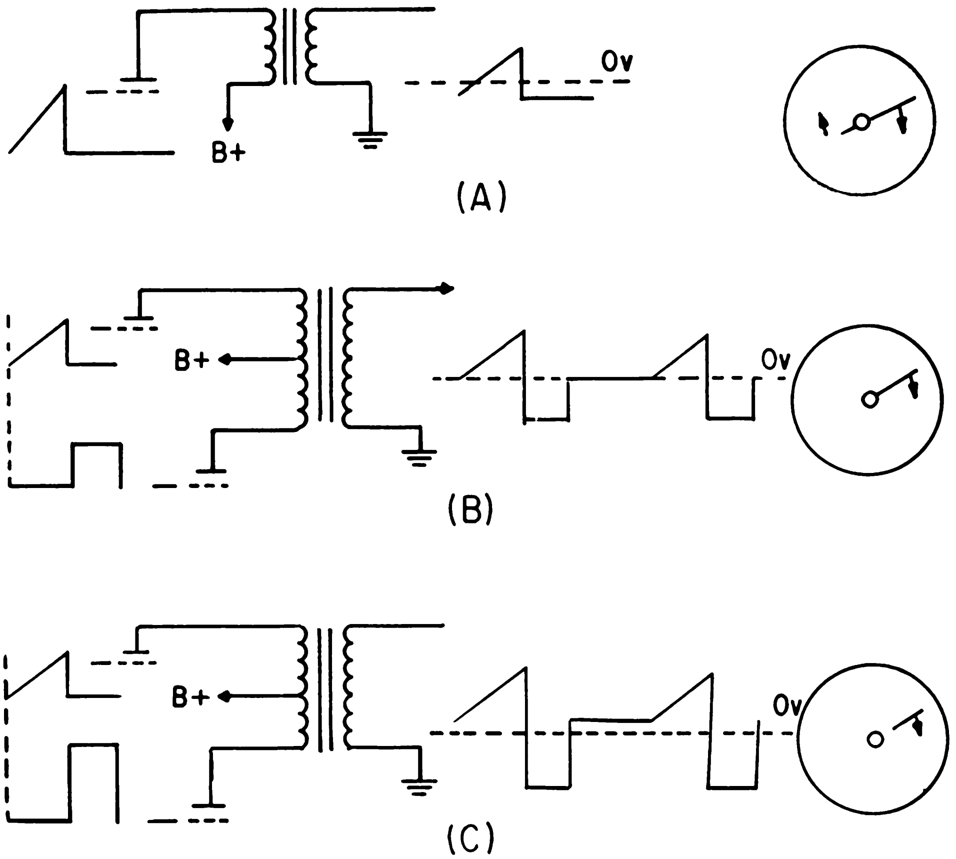
Figure 10-17.—Electromagnetic azimuth yoke, relationship between sweep direction and yoke position.



AT.523

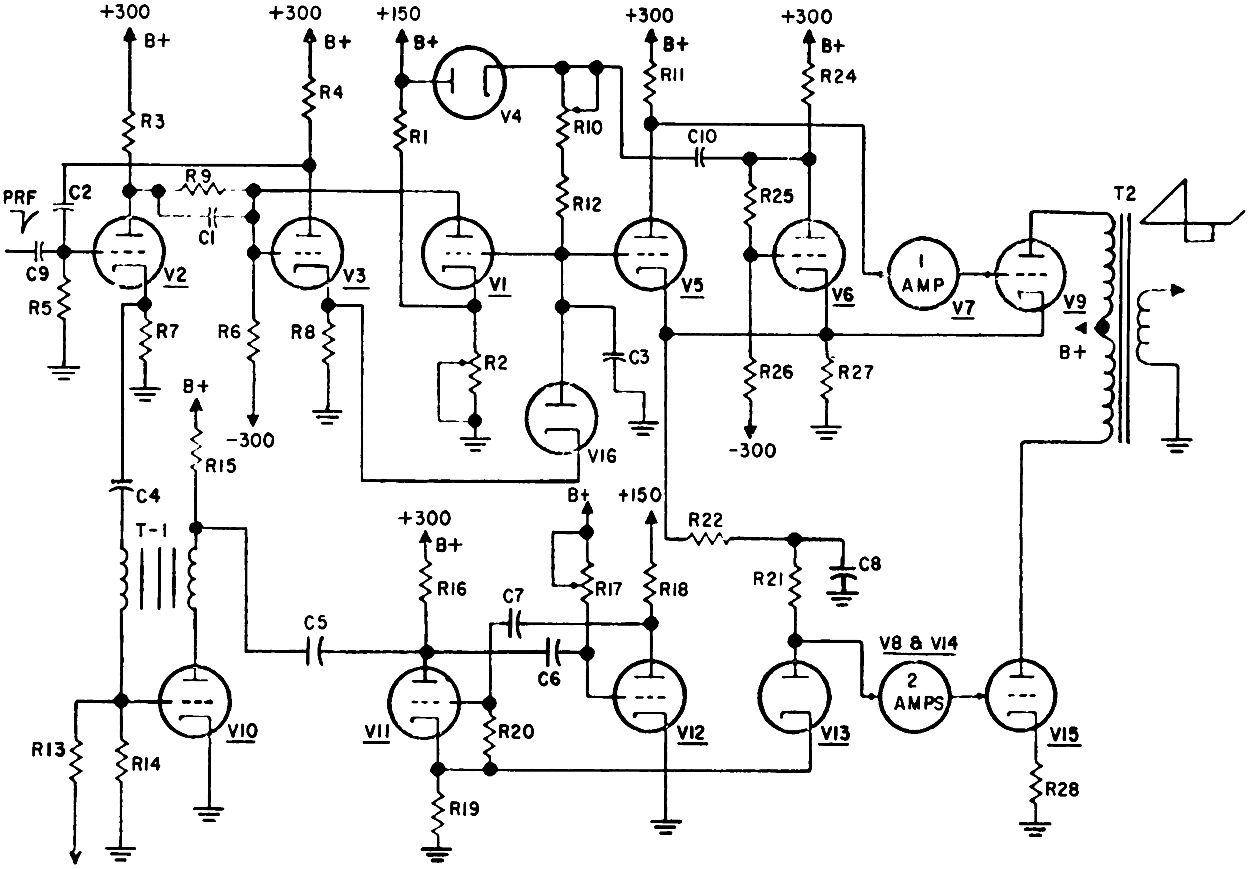
Figure 10-18.—PPI-scope deflection waveforms. (A) No compensation or undercompensation; (B) balanced compensation; (C) overcompensation.

will be in one direction and the sweep on the scope will start from the same point each and every sweep. The scope is blanked at all times except during the sweep time; therefore, only the correct sweep will be present on the scope. If the square wave is too small, the scope will be undercompensated. If the square wave is too large, (fig. 10-18 (BC)), the scope will be overcompensated and an open center will appear on the scope. This open center is undesirable in this circuit.

Circuit Theory

For the following discussion, refer to figure 10-19. The tubes V2 and V3, with associated parts, constitute a multivibrator. In the static state, V2 is conducting and V3 is cut off. An input trigger is applied to the grid of V2; since V2 is conducting in the static state, the trigger must be negative. When the conduction of V2 decreases, the plate voltage rises. This increase in voltage is coupled to the grid of V3, which is driven into hard conduction. The plate voltage of V3 decreases, and this change is coupled to the grid of V2. The discharge of C2 through R5 holds V2 cut off until the sweep-stop tube conducts. The sweep-stop tube is V1, which will be discussed later.

The diode V16 is the switch tube for the sweep generator. In a static state, V16 is conducting and C3 is held at a low-positive voltage. When V16 is cut off, C3 will charge through R12 and R10. V16 is cut off by its cathode being driven to a positive voltage. The cathode of V16 is driven positive when V3 conducts. When



AT.524

Figure 10-19.—PPI sweep circuit, simplified schematic.

V16 is cut off, the charge on C3 increases at a sawtooth rate. The sawtooth is applied to the grid of V1 and V5. V1 is the sweep-stop tube, and it is held cut off in the static state by a positive voltage on its cathode. A voltage divider is formed by R1 and R2 from B+ to ground. R2 is variable, and it is used to adjust the bias on V1. As the voltage on the grid of V1 rises, the bias decreases; V1 will conduct when the bias is overcome. When V1 conducts, a drop in voltage is seen at the right end of R9 and the grid of V3. The decrease in voltage at the grid of V3 will decrease plate current. The rise in plate voltage of V3 is coupled through C2 to the grid of V2, driving V2 into conduction. The plate voltage of V2 decreases and V3 is driven into cutoff, which places the multivibrator back in the static state until another trigger arrives at the grid of V2. The sweep ends whenever V1 conducts. The amplitude of the sawtooth required to drive V1 into conduction is determined by the setting of R2. If the arm of R2 is moved down, the voltage at the cathode of V1 increases and the sawtooth on the grid of V1 must rise to a higher amplitude to fire V1. The sweep capacitor must charge for a longer time; therefore, the sweep time and amplitude will increase. R2 is adjusted for the correct amplitude and then R10 is adjusted for the correct sweep time. R2 is the amplitude control and R10 is the sweep time control. If R2 is adjusted first, the two controls will not interact.

The sawtooth at the grid of V5 is amplified and the negative-going sawtooth at the plate is coupled to V7, amplified, inverted, and

the grid of V9. The positive sawtooth
the grid of V9 causes the current to
hrough the tube at the sawtooth rate.
oth of current through the plate wind-
induces a voltage into the secondary,
oltage causes a sawtooth of current
ndary.

awtooth at the cathode of V6 will be
and from the plate of V6, a positive-
ooth will be fed back to the top of R10.
e at the top of R10 rises during sweep
ing the effective voltage constant. The
is the disconnect tube for the boot-
uit.

cathode of V9, V6, and V5, a saw-
oltage is developed across the unby-
thode resistor. In parallel with R27
cathode of V5, another network is
e ground. This network consists of
V13 and R19 to ground. A capacitor
d from the junction of R22 and R21
. C8 charges to the average of the
t the top of R21. Therefore, a con-
age at the plate of V13 will rise to
of C8. At the plate of V13, a square
be developed as V13 is cut off and on.
re wave is amplified and coupled to
f V15. A square wave of current is
in the plate winding of V15 and a
induced in the secondary. This volt-
ause a square wave of current in the
, in the opposite direction to the saw-
urrent. The square wave must be
at the end of the sweep time. V13
with a positive voltage on its cathode.
ve voltage to cut off V13 is developed
V11 into conduction. V11 is driven
conduction by the positive-going volt-
the plate of V12, when V12 is cut off.
off by a negative pulse from a single-
king oscillator, V10. V11 and V12,
iated parts, constitute a free-running
tor. The time that V11 is conducting
o the time that V12 is cut off. This
ontrolled by the setting of R17. R17
d for the proper compensation. If
f R17 is moved up, the time duration
mpensation gate will increase. Too
pensation results in an open-center
on on the scope.

re that the compensation gate is gen-
the end of the sweep, a square wave
is taken from the cathode of V2; the
portion of the square wave occurs
eep time. The square wave is differentiated by the coupling capacitor C4 and R14. At the end of sweep time, a positive pulse will trigger V10 and a negative pulse is coupled from the bottom of R15 through C5 and C6 to the grid of V12. This pulse will synchronize the free-running multivibrator (V11 and V12). Therefore, the compensating gate always occurs at the end of sweep time.

MARKER CIRCUITS

Marker circuits consist primarily of range marks (fixed and variable), an azimuth marker, and a marker-mixer circuit.

The primary function of the range marker circuit is to provide range markers to be used in determining range to targets. It also supplies a gating pulse to the intensity gate circuit on normal operation. It consists of a range marker gate, range marker gate cathode follower, range marker switch, range marker oscillator, range marker squaring amplifier, and the final amplifying and shaping circuit called the range marker generator. The output of the range marks are fed to a marker mixer.

The discussion of range marker circuits is contained in chapter 9 of this manual.

The azimuth marker is a line produced once each scan to provide the operator with the necessary bearing information. The azimuth-marker circuit generates the electrical pulses which appear as azimuth markers. However, these pulses are not fed directly to the indicators but are fed through the marker-mixer circuit where they are combined with other markers.

The inputs to the marker-mixer circuit are range marks from the range marker circuits and azimuth markers. The function of this circuit is to further amplify these markers before they are fed to the indicators.

Azimuth Marker

The azimuth-marker synchro in the antenna is excited by the azimuth-marker exciter, which is a Hartley type oscillator whose 4000-Hz sine-wave output is applied across the rotor of the azimuth-marker synchro. The rotor of the azimuth-marker synchro, in any position, induces in the stator a 4000-Hz voltage. This voltage varies in amplitude in a sinusoidal manner from zero to maximum in each 180° of rotation of the antenna. The 4000-Hz voltage is then applied to the stator of the differential synchro in the antenna control. The voltage induced in the rotor of the differential synchro is shown in figure 10-20.

The output of the differential synchro is connected to two grid limiters which limits the 4000-Hz voltage until it appears as shown in figure 10-21. This action causes the nulls at 180° and 360° to be very narrow.

Consider the static condition of V149 and V151 in figure 10-22 before the arrival of the signal at the grid of V149. The bleeder network R291, R292, and R293 places a bias voltage on the grid of V149, which causes this grid to be at or very near cutoff. The voltage divider R295, R296, and R297 places the grid of V151 at or near zero bias; in this condition, it will oscillate. Therefore, in the rest or static condition, we may consider V149 cut off and V151 oscillating. When the envelope of 4000-Hz voltage is applied to the grid of V149, it will conduct on the positive half of each 4000-Hz alternation. As V149 conducts, its plate voltage is lowered and C187 and C188 assume a d-c average charge corresponding to the average voltage at the plate of V149. This voltage drop lowers the potential at the junction between R296 and R298 and also lowers the voltage at the grid of V151 so that it will not oscillate. Therefore, when a signal is present that will drive the grid of V149 far enough in a positive direction, V151 is biased far enough negative so that there is no output. When the signal drops to zero or into a null point, the grid of V149 goes to cutoff and no plate current is drawn. The grid of V151 will be driven to or near zero potential and V151 will oscillate, causing a marker on the scope. It is obvious that the mark will only be seen during a null, and a relay is provided to eliminate the unwanted null.

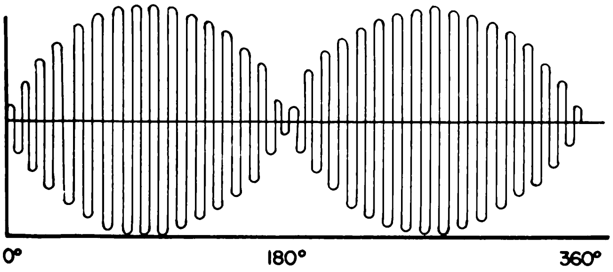


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Figure 10-20.—Azimuth-marker exciter output.

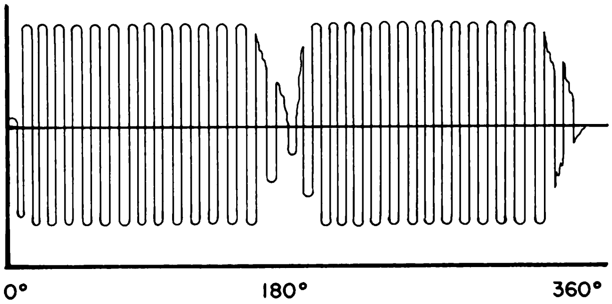

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Figure 10-21.—Azimuth-marker differential synchro output.

Marker Mixer

The method of combining all the various markers is accomplished by the tubes V1, V2, and V3. (See fig. 10-23.) V1 has the range markers applied to its left grid and the right grid is returned to the variable-delay trigger tube. The TD marker is fed directly to the right grid of V1 and will appear on the indicator as a variable marker when the control unit controls are properly set up for TD marker operation.

V2 has its left grid returned to a cable marked L.A.B. This cable would normally be coupled to the low-altitude bombing equipment and place the tracking pip from the bombing equipment on the radar indicators. The right grid of V2 is returned to a cable marked IFF-IR. This cable, normally attached to the IFF equipment, applies the interrogator response return, which is the IFF display on the radar indicators. In operating the IFF and radar system together, the radar transmitter pulse is used to trigger the IFF equipment, which can then be used to interrogate another IFF equipment. The coded return from the other IFF is then applied to the radar indicators. The distance from the transmitter pulse to the first return will be the distance from the radar to the target and the bearing will be determined by the position of the return on the indicators.

V3 has its grid returned to R300 (fig. 10-22), the azimuth-marker amplitude control. The output of the azimuth-marker circuit, a 1-MHz sine wave, is applied to this grid and will appear on the indicators as a sudden reduction in bias for several sweeps, giving the appearance of a bright line at the marker control heading.

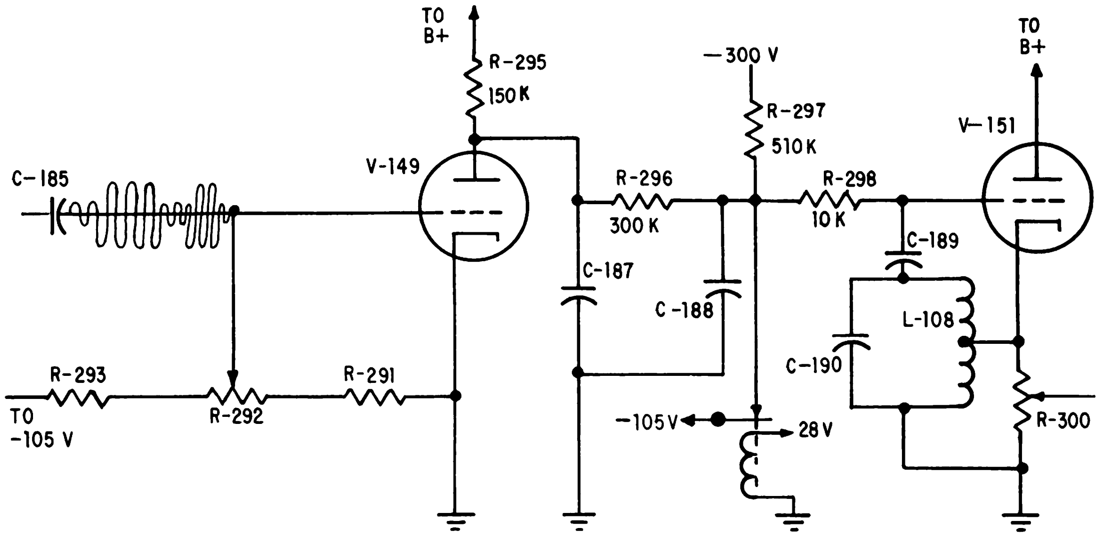

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Figure 10-22.—Azimuth-marker oscillator circuit.

The markers are all combined in the common cathode circuits of the marker mixers and at the junction point of the two cathode resistors R5 and R6. The signal across R6 is coupled through C2 to the grid of V4, one of the marker-output tubes. Also, the signal or signals are coupled through C3 to the grid of V5, the other marker-output tube. Each of these marker-output tubes controls the markers applied to an indicator.

The combining point in any radar system is its indicating device. V6 combines the video from the receiver and the markers from the marker-output tubes. V6 and V7 would be located in the indicator.

The video from the receiver is positive-going video pulses, which have been acted on by the video mixing circuit and the receiver. These positive-going video signals appear negative in the plate of the video-marker mixer V6. Into the right-hand grid of the video-marker mixers are fed the range markers, the amplitude of these markers being controlled by the marker brilliance control R11. Note that the cathode of V6 is unbypassed, so that the cathode would tend to follow the video-frequency rise on the grids of both sides of the tube. This degeneration improves the fidelity, or frequency response, as cathode degeneration will do, although the cathode resistor, R13, is quite small by comparison with the plate-load impedance. Also to improve the frequency response in the plate is the high frequency response peaking circuit of L1.

The negative-going video and markers are coupled through C6 to the grid of the video amplifier, V7. The signals in the plate would be positive-going. In the cathode circuit is the degeneration control, R19, the master brilliance control. In order to simplify the explanation of this control, it should be pointed out that adjusting the resistance of R19 will in no way change the bias on the tube, but by controlling the amount of degeneration present in the cathode, the amplitude of the plate signals can be controlled. The simple deduction would be to say that the increased resistance of R19 would decrease conduction through the amplifier, or reduce the output, and that a decrease in the resistance of R19 would increase the amplitude of the signals in the plate of this amplifier. In the plate circuit is the high frequency peaking component, L2. The positive output from V7 is fed to the final video amplifier.

AZIMUTH STABILIZATION

Most azimuth stabilization systems are similar, and an understanding of one system will provide information that will be helpful in the comprehension of other systems.

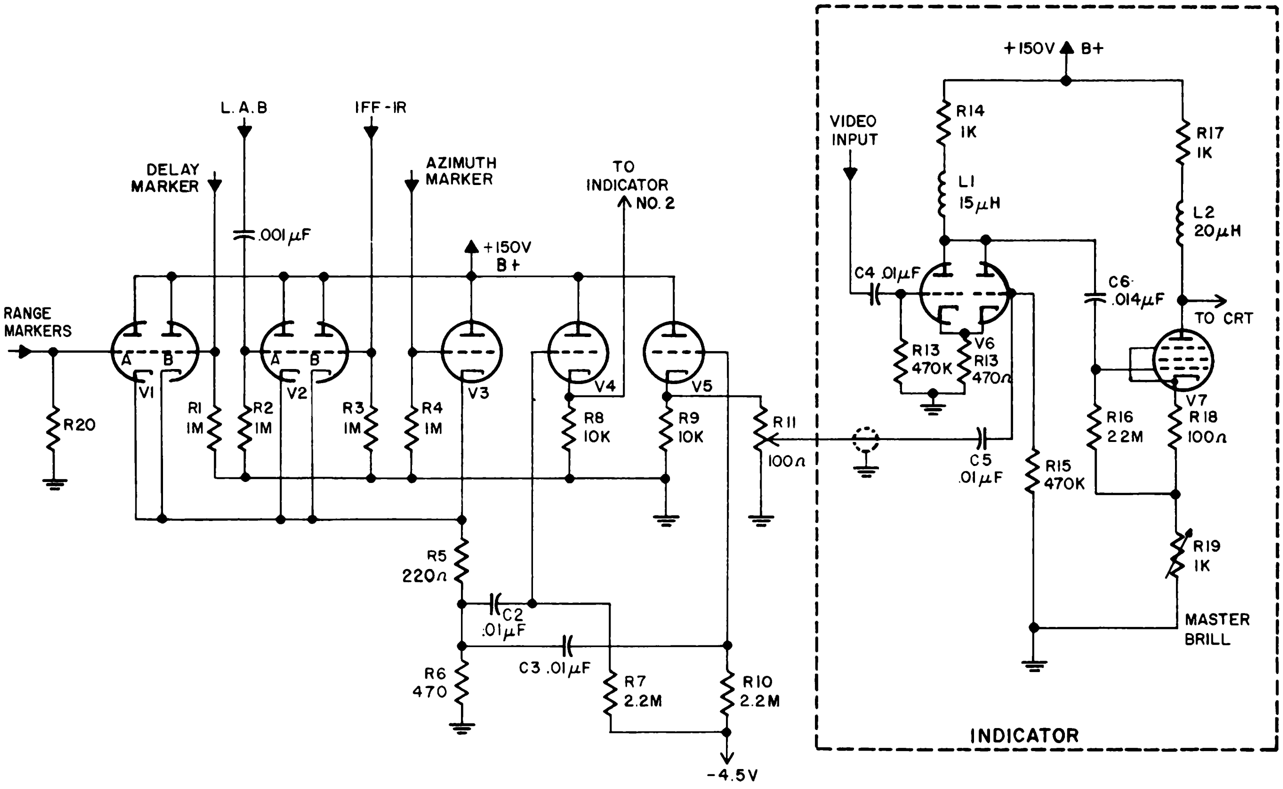

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Figure 10-23.—Marker and video mixer schematic.

An azimuth stabilization system stabilizes the indicator screen presentation, causing the display to remain rotationally fixed despite changes in the heading of the aircraft. By this means, a definite compass relationship is established for the indicator screen, and radar target echoes appear in proper position with respect to the top center of the screen, which represents magnetic north. The stability of the indicator presentation also facilitates search during rough weather or moderate maneuvering of the aircraft.

In the following discussion of azimuth stabilization, an instrument called a fluxgate compass is used. The fluxgate compass employs most of the principles relative to so-called "earth field inductors," and later model compasses operate on those same principles.

Stabilization of the indicator screen pattern is accomplished by signal voltages controlled by the master indicator of the fluxgate compass (also called fluxvalve compass) in the aircraft. These signals are used to control the angle of the sweep trace on the screen in accordance with the instantaneous azimuth position of the scanner.

In order to explain the theory of operation of azimuth stabilization, it is necessary to analyze briefly one of the compass systems used. This is necessary since in an equipment that contains azimuth stabilization the compass that controls the stabilization is an intricate part of the system. The GYRO FLUXGATE COMPASS SYSTEM of the aircraft is a remote-indicating earth-indicator compass, which consists of a gyrostabilized fluxgate, transmitter, an amplifier, a master indicator, and one or more synchro remote-indicator repeaters. (NOTE: The term "gyro fluxgate" is a registered trade name of the Bendix Corporation.) The fluxgate element is stabilized in the horizontal plane by an electrically driven horizon gyro. The gyro head contains a rolling-ball type of erecting system, which maintains the gyro axis in the vertical plane by setting up a restoring force when the axis becomes displaced.

The transmitter portion contains the sensitive element of the system, the fluxgate unit, which consists of three equal legs forming a triangle; this unit is established and maintained in the horizontal plane by the action of the gyro. Each leg consists of two strips of a magnetic alloy used as a core upon which are wound a primary and a secondary coil. The primary coils are connected in series and are excited by an oscillator circuit in the amplifier. The secondary coils are delta connected, with leads tapped off at the points where the three coils join. These leads, and the single lead which supplies the excitation current, are brought out through hairsprings on the gimbal rings. The primary coil of each leg is wound in such a manner that when the leg is at right angles to the magnetic field of the earth the exciting alternating current produces opposing fluxes in each strip which neutralize each other and induce no voltage in the secondary. This exciting current saturates the core on the peak of each half cycle.

When the leg is parallel to the earth's magnetic field, the earth's flux tends to oppose the flux in one alloy strip and to aid the flux in the second strip. The partial cancellation of the flux in the first strip prevents its reaching saturation at the same time as the second strip, and its flux continues to change after the second strip has reached saturation. The flux difference thus set up induces a voltage in the secondary. When the current through the primary decreases to a point where the flux starts to drop below the point of saturation, a voltage in the opposite direction is induced in the secondary. This occurs because the flux in the first strip (in which partial cancellation exists) drops below the saturation point before the flux in the second strip, thus producing a flux change in the opposite direction. Since saturation occurs twice each cycle, and since secondary voltages are induced at the start and again at the finish of each period of saturation, the frequency of the induced voltage is double that of the primary voltage.

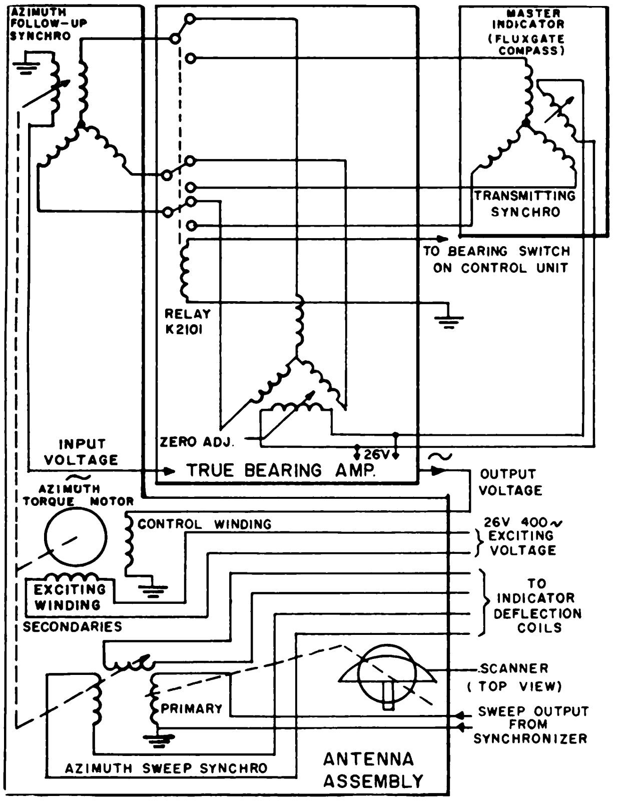
Three signal voltages, which generally are of three different magnitudes, are obtained from the fluxgate secondary coils, and are applied to the stator coils of a coupling synchro contained in the master indicator.

The voltage induced in the rotor winding of this synchro is fed to the fluxgate amplifier, which develops sufficient power to operate a 2-phase induction motor which is also in the master indicator. The fluxgate amplifier includes an extremely stable oscillator that is used to furnish excitation power for the fluxgate and another oscillator which provides voltage for the continuously excited winding of the 2-phase induction motor in the master indicator. The excitation voltage applied to the induction motor is necessarily at a frequency of twice that of the fluxgate excitation voltage in order to equal the frequency of the fluxgate output.

The 2-phase induction motor in the master-indicator phase unit has its stator wound in quadrature (two windings at right angles to each other). The control winding is energized by the amplified signal from the synchro rotor, and the exciting winding receives its power from the oscillator in the amplifier. When both windings of the induction motor are energized by voltages having a phase difference of 90°, the motor rotates and drives the synchro rotor through a gear train until the null position is reached. When this occurs, the voltage induced in the rotor drops to zero; the output of the amplifier also becomes zero; and since only the excitation winding of the induction motor is energized, the motor stops. The position of the synchro rotor is therefore determined by the position of the fluxgate with respect to the earth's magnetic field; consequently, when the aircraft turns, changing the azimuth relation of the fluxgate to the earth's magnetic field, the synchro rotor and attached indicator pointer are turned by the induction motor through the same angle in the same direction. When the synchro rotor reaches the null position, the master indicator shows the magnetic heading of the aircraft. A transmitting magnesyn, which is also turned by the induction motor, provides controlling voltages for remote-indicating repeaters.

Analysis of Azimuth Stabilization

A simplified schematic of the azimuth stabilization section of the radar that will be used in this analysis is shown in figure 10-24. The MASTER INDICATOR of the fluxgate compass system contains the transmitting synchro used



AT.529

Figure 10-24.—Analysis of azimuth stabilization.

with this azimuth stabilization system. The rotor of the transmitting synchro is mechanically coupled to the shaft that drives the pointer of the master indicator. As the aircraft changes its heading, the rotor correspondingly changes position at a one-to-one ratio. The stator of the transmitting synchro is electrically coupled to the contacts of relay K2101. This relay is energized by the operation of the bearing switch on the control unit of the radar system. By referring to figure 10-24, it can be seen that K2101 must be energized before the output of the transmitting synchro can be utilized in stabilization.

The ZERO SET SYNCHRO is utilized to zero set the PPI sweep position when the output of the transmitting synchro is not used, which is during relative bearing operation. The stabilization system will first be described as it relates to relative bearing operation; later it will be shown how azimuth stabilization is provided when the transmitting synchro of the aircraft compass system is connected to the azimuth followup synchro. When on relative bearing operation, the indicators are nonstabilized and the top of the indicator represents the heading of the aircraft; the targets are displayed with respect to the heading of the aircraft. The rotors of the zero set synchro and the transmitting synchro of the fluxgate compass are supplied excitation voltage from the same source. The zero set synchro is adjusted manually. Its positioning will be discussed later.

The stator of the AZIMUTH FOLLOWUP SYNCHRO is electrically coupled to either the stator of the transmitting synchro in the fluxgate compass or the stator of the zero set synchro. The stator that is used for coupling depends upon the position of K2101. The rotor of the followup synchro is mechanically connected to the azimuth torque motor and the secondaries of the azimuth sweep synchro. The phase relationship between the rotor of the transmitting synchro or the zero set synchro determines the amplitude and polarity of the signal developed at the rotor of the followup synchro. When, for example, the rotors of the followup and the zero set synchros are 90° displaced, as shown in figure 10-24, there will be no signal at the rotor of the followup synchro. If, however, the zero set rotor is turned 10°, an error signal will be introduced into the rotor of the azimuth followup synchro. The amplitude of the error signal produced will be dependent upon the amount of displacement between the rotors. The polarity or phase of the signal will depend upon the direction of displacement. The error signal is fed to the servoamplifier input of the true bearing amplifier which drives the azimuth torque motor.

The AZIMUTH TORQUE MOTOR is a 2-phase induction type motor. The fixed voltage winding of this motor is connected to the same power source that supplies the rotors of the transmitting and the zero set synchros. The control winding is connected to the output of the true bearing amplifier. The amplitude and phase of the error signal applied to the control windings depend upon the amount and direction of displacement of either of the two exciting rotors (zero set or transmitter). The azimuth torque motor turns in a direction that is determined by the phase relationship of the voltages applied to these two windings. Since the torque motor is mechanically coupled to the azimuth followup synchro rotor and as the motor turns, it drives the followup rotor to a new null relationship with the rotor of the zero set synchro. As the rotors once again approach their 90° relationship, the amplitude of the error signal decreases, thus decreasing the amplitude of the voltage applied to the control winding of the torque motor. When the rotors of the zero set and the followup synchros are once again displaced by 90°, there is no longer a signal applied to the control winding and the torque motor stops. As previously stated, the azimuth torque motor also turns the secondaries of the azimuth sweep synchros; thus, shifting the position of the azimuth sweep secondaries changes the position of the sweep on the indicators. For example, assume that the antenna is in a dead ahead position, with the sweep pointing to the top of the indicator. Then, by adjusting the zero set synchro to a setting of 10°, which shifts the sweep secondaries by 10°, the sweep position would move to 10°.

The primary (rotor) of the azimuth sweep synchro is mechanically coupled to the antenna; thus, when the antenna rotates, the primary winding is also rotated. The primary winding is supplied with sweep voltages from the radar synchronizer. These voltages are induced into the secondary coils with a variation of phase and amplitude for each coil, depending upon its instantaneous angular relationship with the primary. The secondary voltages are applied to the vertical and horizontal coils of the PPI indicator. By means of these voltages, the angular deflection of the sweep trace on the PPI indicator is controlled in accordance with the instantaneous azimuth position of the radar antenna.

The example cited previously utilized the movement of the zero set synchro (manual adjustment) to move the secondaries of the azimuth sweep synchro and hence the PPI sweep. The same comparison may be made with the transmitting synchro. This synchro changes as the heading of the aircraft changes, and this action coupled with the operation of the system just discussed is the analysis of azimuth stabilization.

Comparison of the True and Relative Bearings

As already explained, changing the aircraft heading changes the positions of the sweep secondaries of the azimuth sweep synchro. This occurs on azimuth stabilization only and the change is automatic. On manual operation the only change that can be made is by varying the position of the zero set synchro. This is not stabilization, for it has no relationship to the movement of the aircraft. The zero set synchro is adjusted on manual or relative bearing operation. The antenna is set on 0° with respect to the aircraft and the zero set synchro is adjusted until the sweep appears at the dead ahead position.

During relative bearing operation, with the azimuth indicating device at the top of the scope, and targets appearing thereon, a change in the bearing of the aircraft will result in a change of position of targets. This is an undesirable feature due to the fact that during the time the targets are shifting position they are hard to observe on the indicators. Refer to figure 10-25 for a visual explanation of this condition. The top of the scope indicates the heading of the aircraft and all targets are displayed relative to this heading; thus, on relative bearing operation, the top of the indicator indicates the heading of the aircraft. In other words, when the aircraft is heading north, the top of the scope is north. When the aircraft is heading in any particular direction, the top of the scope is also that direction.

The fluxgate compass controls the position of the sweep on the indicators during true bearing operation. As the fluxgate compass follows the aircraft's changes in heading, the error signals coupled to the azimuth stabilization system change the position of the sweep. These changes in position occur at a one-to-one ratio. Thus, if the aircraft heading changes a certain number of degrees, the sweep secondaries will also change a like amount. Refer to figure 10-26 for a comparative analysis of true bearing operation.

In this operation the azimuth indicating device, as on relative operation, represents the heading of the aircraft provided the marker control on the radar control box is set to 0°. The action of moving the sweep secondaries to correspond with changes in the heading of the aircraft causes the azimuth indicating device to shift. Hence, the azimuth indicating device will always indicate the heading of the aircraft and, when on true bearing operation, the top of the scope always indicates north (provided the marker control on the radar control box is set to 0°). As the aircraft changes its heading, the targets remain in their position

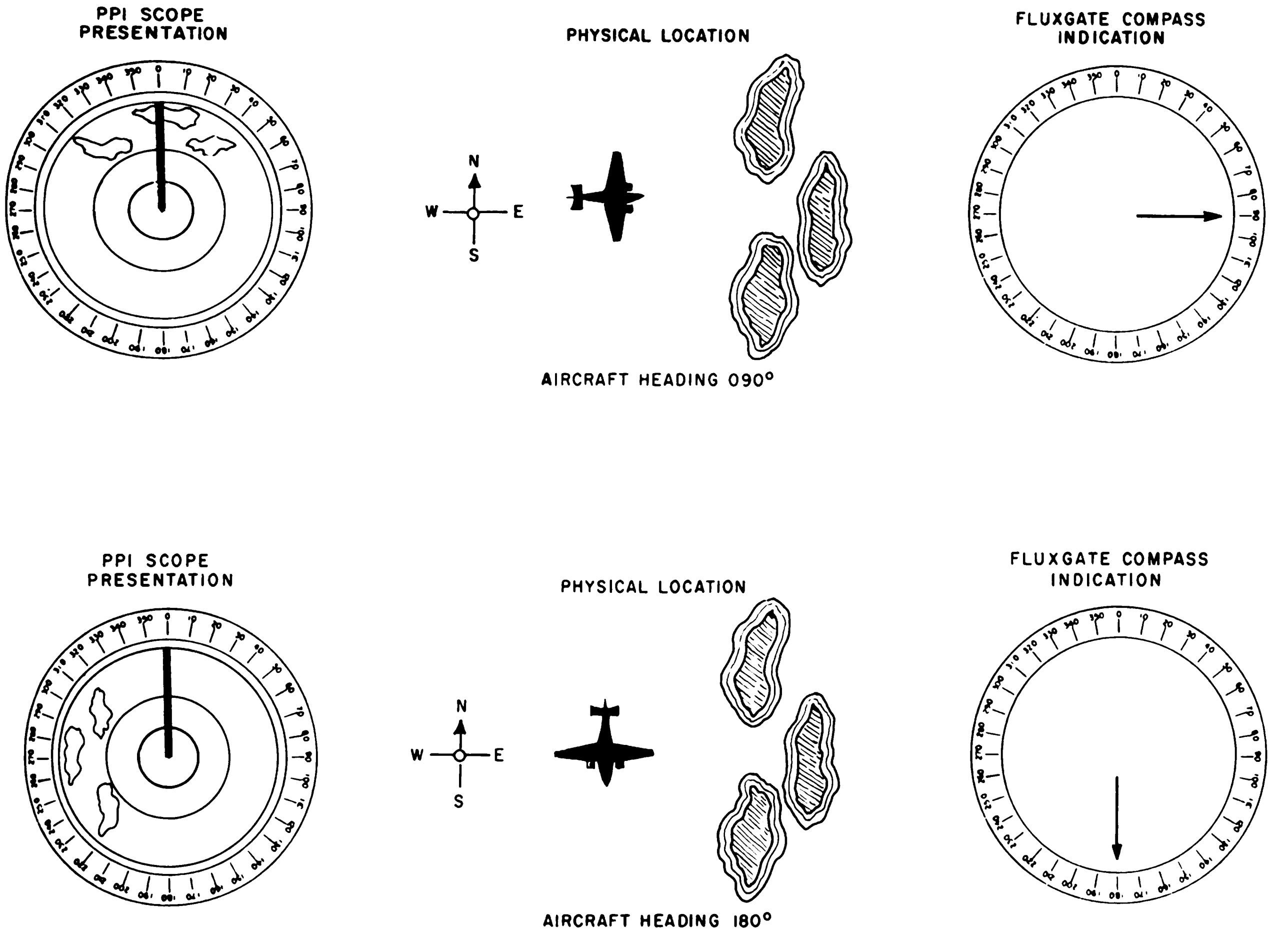


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Figure 10-25.—PPI-scope, relative bearing presentation.

on the scope and only the azimuth indicator moves. Thus, the targets remain fixed, are always visible, and their relationship to the aircraft can be checked with the azimuth indicating device.

The top of the indicator represents magnetic north when the VARIATION is not set in, and true north when the variation has been set in. Variation is the angle between magnetic north and true north and differs at different points on the earth. The number of degrees of variation may be obtained from navigational charts. Some compass systems provide a means whereby variation may be added into the system; thus the compass will then indicate true north, and a radar slaved to the compass will also indicate true north. In some aircraft installations that are equipped with a compass that does not provide this correction feature, a variation differential generator is included. This generator is between the transmitting synchro of the compass and the azimuth followup synchro in the radar. By adjusting this generator to the local variation, it is possible to correct the radar to true north.

True Bearing Amplifier

The input to the true bearing (servo) amplifier (fig. 10-27) is obtained from the rotor of the azimuth followup synchro. This error signal is applied across resistor R1 (sensitivity

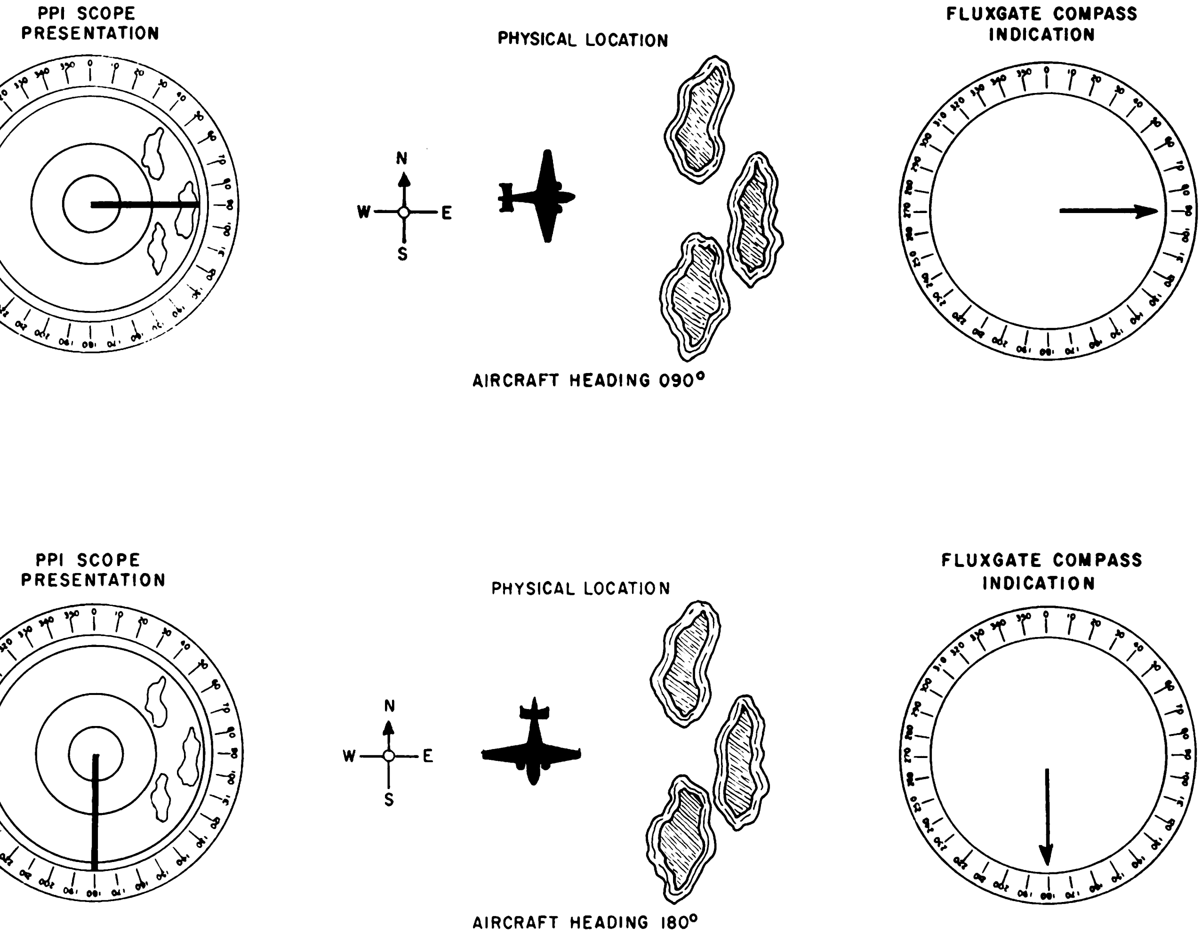

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Figure 10-26.—PPI-scope true bearing presentation.

tment) which is paralleled by the primary
put transformer T1. The amplitude of this
l is determined by the amount of change
e aircraft heading, and the phase is deter-
l by the direction of the change. The sig-
s transformer coupled to the grids of V1
is the true bearing amplifier discrimi-
. The signals on the grids of V1, due to
ransformer action, will always be 180°
f phase. The plate voltages, due to the
former connections, are always in phase.
the grid that is in phase with the plate
letermine which half of the duotriode con-
the hardest.

nen the grid and plate of V1 (A) are in
, its conduction charges the capacitors in the plate circuit. The plate current circuit is from the plate of V1 (A) through the source potential winding, plus to minus, then up through resistor R5. The current flowing through R5 develops a negative voltage at the bottom and charges capacitor C6. C6 in conjunction with C5 provides an a-c filter path to ground. The current flows from the junction point to resistors R4 and R5 back to the center tap of transformer T1. The path is then completed back to the cathode through the resistor R2 and the balance pot R3. During this same time, although V1 (B) has its grid negative and plate positive, it may still conduct a little. Its conduction path from the plate through the source potential causes current to flow through resistor R4 and

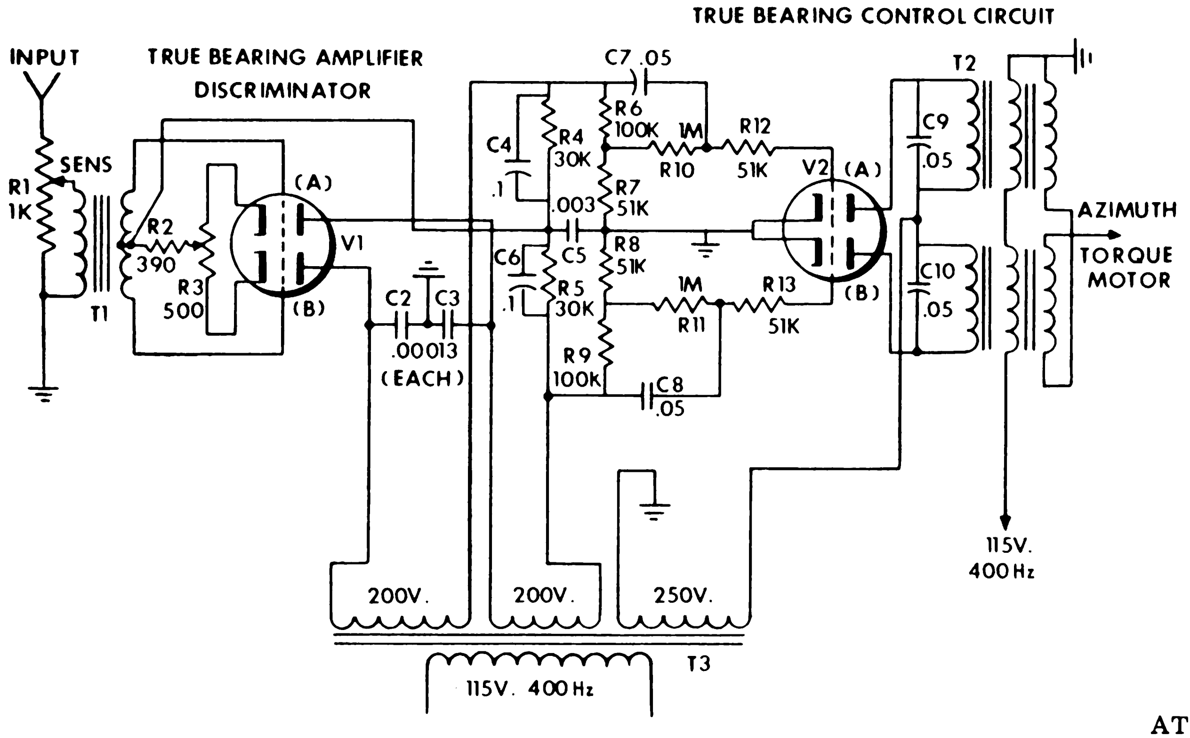

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Figure 10-27.—True bearing amplifier.

develop a negative voltage at the top of R4. The negative voltage developed at the bottom of R5, however, far exceeds the negative voltage developed at the top of R4. Thus the voltage measurement from R5 is negative to positive. The voltage thus developed is coupled to the grids of the output control tubes.

The grid of V2 (B) is more negative than the grid of V2 (A). Any portion of the a-c signal not filtered out through capacitors C4, C5, and C6 is coupled through C7 and C8 to the grids of V2. In addition, the d-c signal developed across R6, R7, R8, and R9 is taken from the junction of the resistors and also applied to the grids. Hence, the grids contain both a-c and d-c components.

When the amplitude of the signal on either grid is too great, grid current is drawn; this limits the conduction of the tube. For example, when the amplitude of the signal on the grid of V2 (A) is excessively positive, grid current will flow through R10 and R12, thus adding to the bias on V2 (A).

The cathode of V2 is tied directly to ground. The voltages applied to the plates of V2 are in phase and conduction depends upon the grid signals that are developed in the discriminator circuit. In the case cited previously where V1 (A) conducted the hardest, the voltages developed in the output resistors made the grid of V2 (B) most negative. Under these conditions, the current flowing through the plate windings of the bottom control winding of the SATURABLE REACTOR assembly, T2, will be less than the current flowing through the upper winding. The current flowing through the control windings of the saturable reactor assembly determines the amount of output signal developed.

The center winding or primary of the saturable reactor assembly is excited by 115 volts a.c. The coupling from the primary to the output or secondary windings is controlled by the conduction through the control windings. The control winding with the least current flow allows the greatest coupling from primary to secondary. The output windings are wound in series opposing. Capacitors C9 and C10 serve to filter the a-c component and give a fairly constant current flow through the control windings.

In the case cited previously, since V2 (B) is conducting the least, the saturation of the bottom section of T2 is less than that of the top section. Under these conditions the voltages developed in the bottom output winding far exceed those developed in the top winding. The polarity of the voltage taken from the output of the saturable assembly will be the same as that from the bottom winding. This voltage is applied to the control winding of the azimuth torque motor.

The rotor of the AZIMUTH TORQUE MOTOR is mechanically connected to the secondaries of the azimuth sweep synchro and the rotor of the azimuth followup synchro. The motor then drives the followup synchro rotor to a new null relationship with the rotor of the transmitting synchro, or zero set synchro, depending upon the position of K2101. One secondary winding of the AZIMUTH SWEEP SYNCHRO (resolver) is connected to the vertical winding of the deflection system, and the other is connected to the horizontal deflection winding.

Refer to figure 10-28 for a descriptive analysis of changes in the azimuth stabilization system when the aircraft heading is changed. With the antenna stopped in the dead ahead position, as shown in (A), an error signal is applied to the true bearing amplifier which causes the azimuth torque motor to turn. The sweep secondaries are then driven in a direction corresponding to the change in the transmitting synchro rotor, as shown in (B). When the aircraft changes its heading, the sweep position on the PPI-scope will change accordingly.

TILT STABILIZATION

The purpose of TILT STABILIZATION is to stabilize the tilt angle of the antenna of a radar system with respect to the earth. If the antenna is left unstabilized, when the aircraft changes its flight angle the antenna follows this change. If the antenna is dead ahead with respect to the aircraft and the plane begins a climb, the antenna will point up, thus losing targets. If, on the other hand, the antenna is pointing to port or starboard and the aircraft rolls to either side, the target returns will again be lost. If the antenna is stabilized with respect to the earth then the target loss, due to changes in the attitude of the aircraft, will be minimized. For example, assume that the antenna is pointing dead ahead in relation to the aircraft and the aircraft goes into a climb; if the antenna is stabilized, it will tilt down and maintain a constant angle with respect to the earth. The same holds true if the antenna is pointing to port or starboard and the aircraft is rolling; the antenna will tilt up or down, maintaining the constant reference with respect to the plane of the earth.

The stabilization range of the radar set which will be used for this explanation is such that if the TILT control is set for 0 the beam is maintained at this angle for aircraft pitch or roll up to plus 30° or minus 30°. If the TILT control is set for other beam angles, these limits vary accordingly.

The tilt stabilization system consists of a gyroscope, servoamplifier, resolver synchro, manual-tilt synchro, tilt-torque motor, damping-signal generator, and the followup synchro. (A diagram of this system is shown in figure 10-29.) The gyroscope unit is separately mounted on the aircraft structure, and the resolver synchro and the servoamplifier are mounted on the antenna-assembly frame. The tilt-torque motor, damping-signal generator, and followup synchro are contained in the tilt-servo unit mounted on the rotary section of the antenna assembly. The manual-tilt synchro is mounted in the radar set control box.

Stabilization is effected by the use of two signals, the resolver-synchro signal and the manual-tilt synchro signal. Separate pitch and roll signals originating in the gyroscope unit are combined in the resolver synchro to produce the single resolver-synchro signal. The manual-tilt synchro signal originates in the followup synchro and provides the tilt stabilization system with continuous information as to the tilt angle of the reflector. This signal passes through the manual-tilt synchro in the radar set control box where it is modified according to the setting of the TILT control. The resolver-synchro signal and the manual-tilt synchro signal, which differ in phase by 180°, are combined at the input of the servoamplifier, and the amplifier resultant, or error signal, is used to control the tilt-torque-motor in correcting the tilt angle of the reflector.

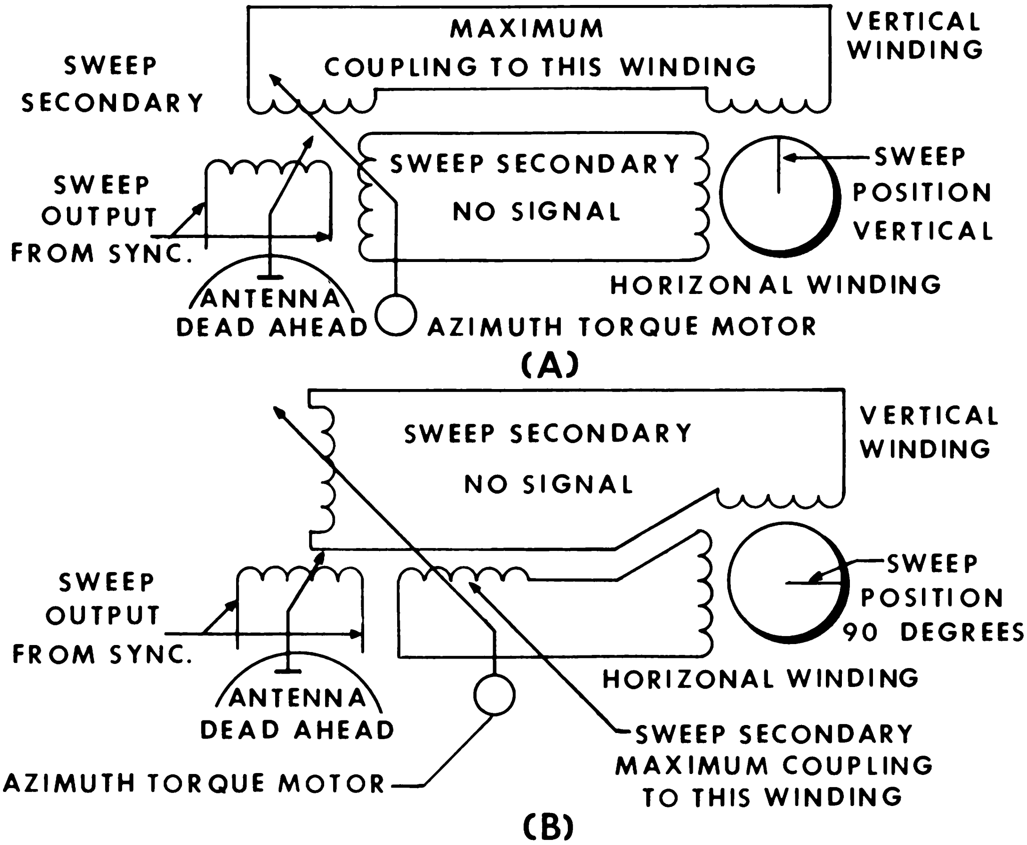

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Figure 10-28.—Analysis of changes in an azimuth stabilization system.

Gyroscope Unit

The gyroscope unit contains the gyro, with its drive motor, erecting mechanism, motor-driven caging and uncaging mechanism, and two synchros. The gyro, powered by a 26-volt, 400-Hz, 3-phase induction motor, establishes true vertical. The caging and uncaging mechanism is electrically operated, and is manually controlled by the GYRO switch on the radar set control. When caged, the gyro is clamped in an approximately vertical position with respect to its housing. CAGING OF THE GYRO prevents it from being damaged when the aircraft is engaged in maneuvers involving pitch or roll in excess of 60°. The gyro develops a normal operating speed of 18,500 rpm; when it is UNCAGED, the rolling-ball type ERECTING mechanism brings the gryo to true vertical and maintains it in this position. The gyro should be uncaged when in use and caged when the equipment is turned off. Although the GYRO switch may be in the UNCAGE position, the gyro is automatically caged when POWER switch is turned off. After the equipment is turned on, the gyro remains caged during the warmup period of approximately 3 minutes, after which time the operation of the caging mechanism is dependent upon the position of the GYRO switch. The schematic diagram of the gyroscope unit is shown in figure 10-30.

The PITCH and ROLL synchros in the gyroscope unit deliver signals to the tilt stabilization system in the antenna assembly in accordance with the departure of the aircraft

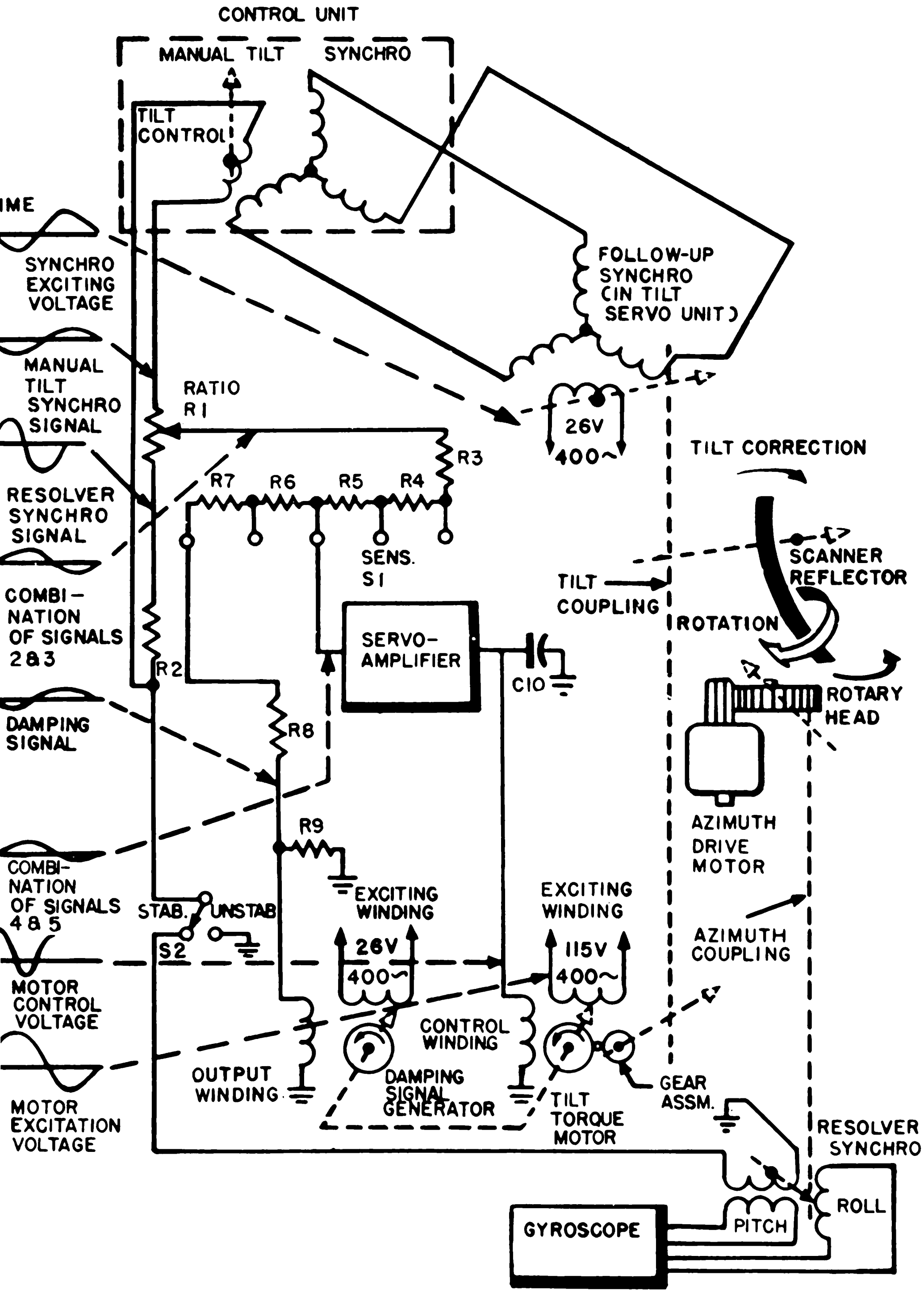

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Figure 10-29.—Tilt stabilization with high-speed antihunt.

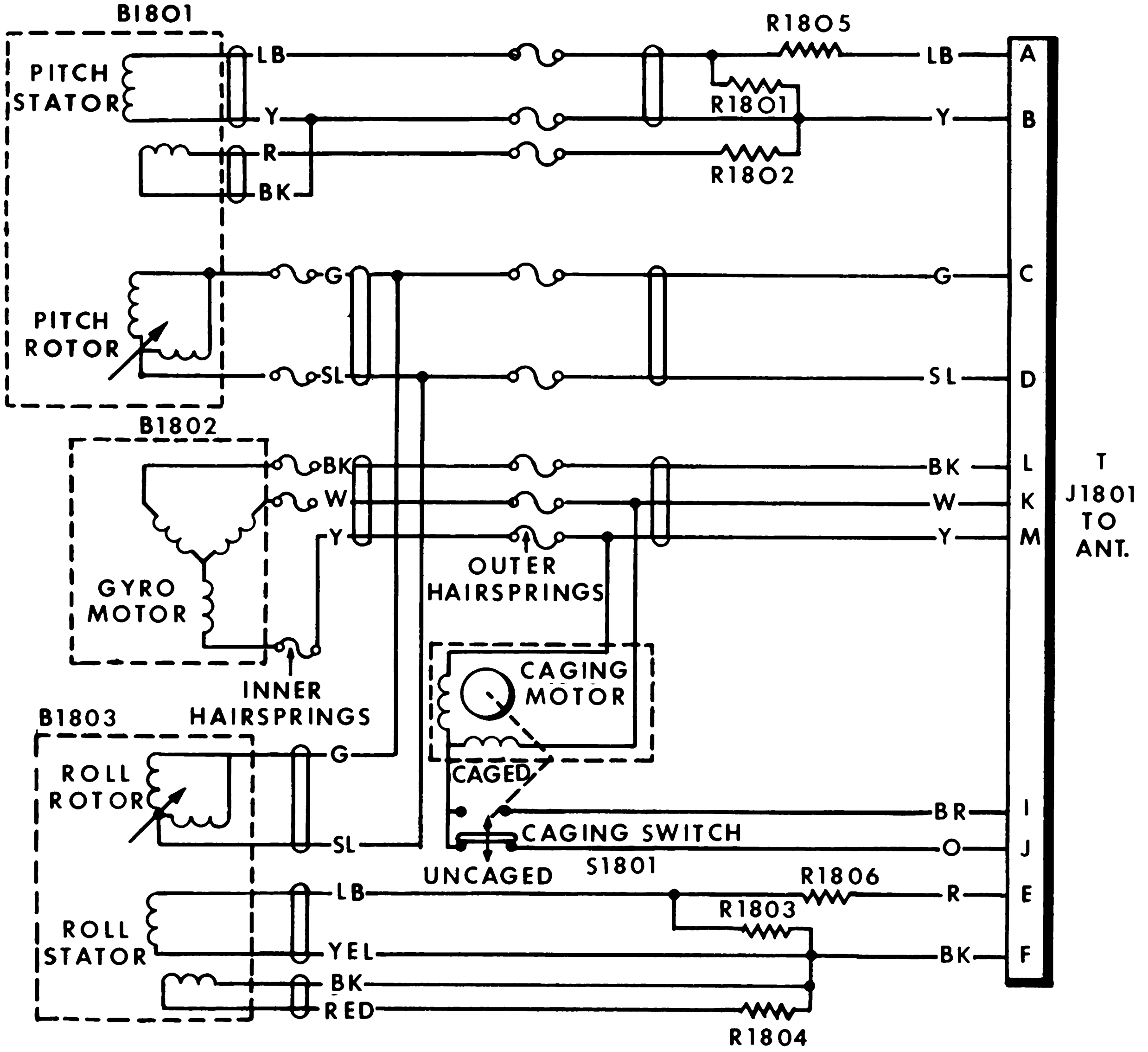

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Figure 10-30.—Gyroscope unit.

from level flight; these signals are used to stabilize the tilt angle of the beam with respect to the horizon. The rotor winding of each synchro is excited by 26-volt, single-phase, 400-Hz a.c. When either of the rotors is displaced from the null point, single-phase voltages are induced in the stators; the phase relationships and amplitudes of these voltages are determined by the direction and degree of displacement.

The stators of the two synchros are rigidly attached to the gyro, at right angles to each other. The rotor of the pitch synchro is mounted with its shaft horizontal, and at right angles to the line of flight of the aircraft. Since the rotor is fixed with respect to the aircraft, and the stator is fixed with respect to the gyro housing, an a-c pitch signal is developed when the rotor is displaced by the pitching of the aircraft.

The rotor of the roll synchro is also mounted with its shaft horizontal, but the shaft is parallel to the line of flight of the aircraft. Since the rotor is fixed with respect to the aircraft, and the stator is fixed with respect to the gyro, an a-c roll signal is developed when the rotor is displaced by the rolling of the aircraft. When the attitude of the aircraft combines both pitch and roll, pitch and roll signals are simultaneously produced by the gyroscope unit. These signals are fed to the resolver synchro in the antenna assembly. (See fig. 10-29.)

When displacement of the gyroscope synchros occurs, a torque is developed at the stator coils, which, if not compensated for, will cause the gyro to deviate from true vertical, thereby introducing errors into the reflector angle of stabilization. To counteract this effect, a balancing coil connected to a load resistor is mounted along with the stator of each synchro. When displacement of the rotor occurs, the magnetic field developed about the balancing coil causes a torque in the direction opposite to that already exerted on the stator, thus insuring stability of the gyro. The gyroscope unit is mounted on the aircraft structure and is provided with a reference base plate which is adjusted to a plane parallel to that of the antenna platform. The component is also provided with a sighting surface to permit alinement parallel to the lubber line of the aircraft.

Resolver Synchro

With the resolver synchro, the pitch and roll signals from the gyro are combined by induction in a rotor coil that is geared to the rotary head of the scanner, with which it rotates in a one-to-one ratio. Because of this mechanical coupling, the resultant resolver-synchro signal used in tilt stabilization experiences the proper variation throughout the scanning cycle to maintain the selected reflector tilt angle with respect to the aircraft for every azimuth position of the scanner. The net effect of tilt stabilization is to maintain a fixed predetermined angle of tilt between the reflector and the true horizontal, while the aircraft experiences the usual variations of normal flight.

The pitch and roll signals developed by the gyroscope unit are fed into the separate stator windings of the resolver synchro. These stator windings are mounted at right angles to each other. The orientation of the rotor is adjusted so that when the reflector is dead ahead, pitching of the aircraft causes maximum pitch signal to be induced in the rotor of the resolver synchro; when the reflector is directed to extreme port or starboard, rolling of the aircraft causes maximum roll signal to be induced in the rotor of the resolver synchro. At intermediate positions of the reflector, combinations of both pitch and roll signals are induced in the rotor. One of these voltages may be either aiding or opposing the other, according to the attitude of the aircraft, with respect to the azimuth position of the reflector.

Servoamplifier

The SERVOAMPLIFIER amplifies the error signal resulting from the combining of the manual-tilt synchro signal and the resolver-synchro signal, and controls the voltage to the tilt-torque motor, which corrects the tilt angle of the scanner.

The servoamplifier uses two resistance-coupled amplifiers, followed by a phase-discriminator stage and a pair of d-c amplifiers working into a saturable-reactor assembly. The output of the phase-discriminator stage, amplified by the d-c amplifiers, controls the a-c voltage that drives the tilt-torque motor. The direction of drive, which determines direction of tilt, is governed by the phase relationship between the exciting voltage and the control voltage of this motor; this relationship is, in turn, dependent upon the phase relationship between the motor-exciting voltage and the error voltage at the input of the servoamplifier.

The scanner is maintained at an angle of tilt with respect to the horizon. This angle is determined by the setting of the TILT control. This condition is achieved by combining the signal from the manual-tilt synchro with the one from the resolver synchro at the input of the servoamplifier. (See fig. 10-29) The signal from the manual-tilt synchro is applied to one side of the ratio potentiometer, R1, and the signal from the resolver synchro is applied, through resistor R2, to the opposite terminal of the same potentiometer, whence they are combined in the servoamplifier. These two signals are 180° out of phase, and when of equal amplitude they cancel each other. When this cancellation is complete, there is no control voltage for the tilt-torque motor, and consequently no tilt action is applied to the scanner.

When the aircraft rolls, the resolver-synchro signal is altered in amplitude, provided the scanner is not directed dead ahead or aft (at

0° or 180° azimuth). When the aircraft pitches, the resolver-synchro signal is altered in amplitude, provided the scanner is not directed at 90° or 270° relative azimuth. As a result, the resolver-synchro signal and the manual-tilt-synchro signal no longer cancel, and an error signal is developed at the input of the servoamplifier. After amplification, this error signal is applied to a phase discriminator, which determines from the phase of the signal whether the reflector must be tilted up or down in order to correct for the roll, pitch, or combination of the two that has just caused the error signal. The output of the phase discriminator drives the proper tilt-servocontrol tube, which then applies the control voltage to the tilt-torque motor by means of a saturable reactor. As the tilt-torque motor corrects the scanner tilt angle, the rotor of the followup synchro, which is coupled to the tilt-torque motor, is turned in such a direction that the manual-tilt synchro signal changes in amplitude to compensate for the change in the resolver-synchro signal. When these two signals cancel again, the necessary correction to the reflector tilt angle has been accomplished, and the tilt-torque motor stops.

The ratio potentiometer, R1, balances the signals from the manual-tilt synchro and the resolver synchro to compensate for possible deviation from the true horizontal of the mounting plane of the gyroscope unit.

This servoamplifier functions similarly to the one discussed under "Azimuth Stabilization" in this chapter, in that the error voltage controls the saturable reactor which provides the variable voltage for the control winding of the tilt-torque motor. (See fig. 10-28.)

In this tilt stabilization system one winding of the TILT-TORQUE MOTOR is continuously excited by 115 volts a.c. The other winding, used to control the starting and operation of the motor, is supplied from the saturable reactors with a-c voltage developed whenever an error signal is amplified by the servoamplifier. The motor torque is obtained by providing approximately 90° phase difference between the control voltage and the excitation voltage, by means of capacitor C10 which is shunted across the control winding. The speed of the motor is dependent upon the amplitude of the control voltage, which in turn is dependent upon the action of the TILT control, tilt stabilization and damping.

Manual-Tilt Control

The scanner tilt angle is controlled by the tilt synchro in the radar set control and is adjusted by means of the TILT control. The tilt synchro is connected with the followup synchro in the tilt-servo unit. Supplied with a steady a-c voltage, this synchro circuit develops the manual-tilt synchro signal in its rotor to control the tilt angle of the beam with respect to the angle of tilt stabilization (approximate horizon). The signal from the manual-tilt synchro is fed to the input of the servoamplifier, where it is combined with the resolver-synchro signal. Control of the scanner tilt angle is therefore dependent upon the resultant sum of these two voltages, and is accomplished through the system used for tilt stabilization, as just described. If the resolver-synchro signal is switched off by means of the STAB-UNSTAB switch S2 on the servoamplifier, the beam-tilt angle is then established only with respect to the aircraft.

Followup Synchro

The followup synchro and the manual-tilt synchro develop the manual-tilt synchro signal. The followup synchro is located in the tilt-servo unit of the antenna assembly. The rotor of this synchro is mechanically coupled to the tilt mechanism so that the rotor movement occurs in synchronism with the tilting of the scanner. The stator windings of the followup synchro are connected to the stator windings of the manual-tilt synchro in the radar control unit. The rotor of the followup synchro is supplied with 26-volt, 400-Hz, single-phase voltage. Voltages of unequal amplitude are induced in the stator windings (fig. 10-28). These voltages are reproduced in the stator windings of the manual-tilt synchro in the radar set control. When the rotor position of the manual-tilt synchro is such that its signal cancels the resolver-synchro signal and produces a null at the input of the servoamplifier, no control voltage is developed for the tilt-torque motor and the scanner tilt angle is not changed. When the rotor is displaced from this position in either direction by resetting the TILT control for a new beam tilt, one signal becomes larger than the other, cancellation is no longer complete, and therefore an error signal is developed which causes the servoamplifier to develop a control voltage for the tilt-torque motor. As the motor drives the scanner to the required tilt angle, a mechanical coupling from the motor turns the rotor of the followup synchro. When the manual-tilt synchro again cancels the resolver-synchro signal at the input of the servoamplifier, the tilt-torque motor stops. The beam-tilt angle thus obtained is determined with respect to the horizontal.

Damping Signal Generator

An a-c generator is geared mechanically to the tilt-torque motor and has an output voltage when the torque motor turns. This is the damping-signal generator shown in figure 10-29. The a-c voltage out of this generator is adjusted to a value equal to the error signal produced with only a few degrees of angular displacement between input and output shafts. This ANTIHUNT or DAMPING voltage is fed to the servoamplifier in such a manner as to be out of phase with the error voltage at all times. As the servo-torque motor turns the output shaft to its new position, the amplitude of error signal will be constantly decreasing to a null of voltage. At some point close to zero angular displacement between input and output shafts, the antihunt a-c voltage will be equal in amplitude but out of phase with the error voltage, so that the signal into the servoamplifier is canceled. The inertia of the output shaft mechanism carries the output shaft beyond this point to where the phase of the amplifier input signal is reversed and starts to increase in amplitude due to the damping signal generator's output exceeding the error signal. This causes a reversal of the output voltage from the servoamplifier to the torque motor prior to reaching a null of the positional error voltage. This reversal of torque causes a braking action which stops the torque motor and the load. This also stops the damping-signal generator and no further error is applied to the amplifier.

Some provision must be made to control the exact amplitude of the net input signal to the servoamplifier so that optimum stability is obtained. This may be done by varying the antihunt or damping generator output so as to cancel out the error signal at the proper angular displacement.

If the antihunt or damping signal is LOW in amplitude as compared to the error signal at the correct cancellation angle, the power to the torque motor will not be removed at the proper angular displacement point. This will cause the output shaft to overshoot the proper angle and oscillations or hunting will occur. These oscillations will gradually diminish to the correct position of the output shaft. If the antihunt or damping signal is HIGH in amplitude as compared to the error signal at the proper cancellation angle, the error signal will be canceled at too great an error angle, or too soon. The output shaft will be stopped with some degree of error angle remaining between input and output shafts. As the output shaft stops, the a-c damping voltage will fall to zero and the remaining error signal will cause the shaft to turn slowly to the correct point. It is of interest to note that the hunting of the scanner is held to a maximum of plus or minus one-half degree of tilt about the angle of stabilization. This, as you can easily understand, is a very close tolerance of error and thus, hunting is adequately eliminated.

GROUND STABILIZATION

Ground position indicating equipment continuously indicates the ground position of a flying aircraft from an initial reference point. One of its functions is to show north-south (N/S) and east-west (E/W) distances from the reference point on direct reading dials. Its primary function is to furnish voltages which will "ground stabilize" a radar display. This is accomplished by causing the PPI display to remain fixed geographically.

Unstabilized search radar produces a PPI display that constantly changes as the aircraft moves across an area. Since the sweep starting point represents the position of the aircraft in the center of an area, it follows that the PPI presentation will change as the aircraft travels. Also, any targets on the scope will move across the scope. If, however, a target is selected and the radar display is ground stabilized, the sweep starting point will change and the targets will remain fixed in place on the scope. The radar continues to "view" only the selected area in which the targets lie, as shown in figure 10-31. For each mile of flight, the origin (start) of the sweep is displaced 1 mile on the indicator in the direction of flight. Thus, the track of the sweep origins becomes the aircraft's flightpath.

Automatic ground stabilization is particularly advantageous in some radar applications. It simplifies the problems of ASW operation by reducing calculations required to fly a sonobuoy pattern; it enables the operator to easily

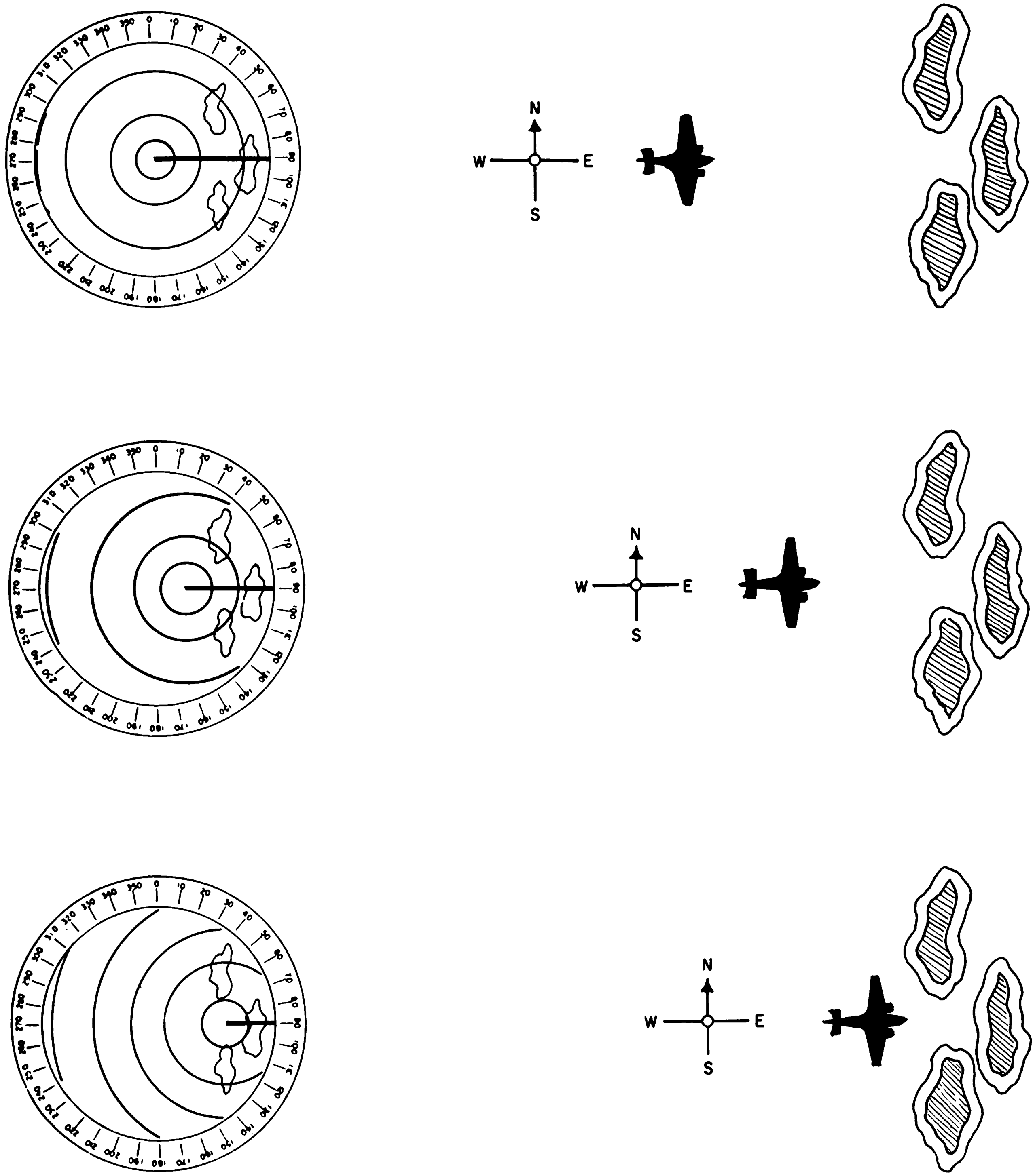

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Figure 10-31.—Ground position indication display sequence.

ablish a track of moving targets such as ps, surfaced submarines, vehicles on land, l airborne aircraft; and also, the ground bilization feature can be used as a homing 'ice from reasonable distances.

The purpose of a ground stabilization system to combine and amplify certain d-c voltages ich are used to properly position the start the sweep on the indicator. These d-c volt- s are developed either by manual control slew helipots or by automatic control from ground stabilization computer.

Four slewing voltages (representing the car- al directions) are supplied and controlled omatically by the associated ground stabili- ion computer. These voltages are combined h another set of four slewing voltages which manually controlled by the radar operator h the manual slew helipots. The combined tages are applied to the grids of the input hode followers, the outputs of which are lied to pairs of push-pull d-c amplifiers ich determine the bias voltages for the as- iated sweep amplifiers in the indicator de- ction system. The starting position of the eeps on the indicator changes as these biases nge, and varies automatically with respect aircraft speed, direction of flight, and wind ocity. (See fig. 10-32.)

MPUTER

As can be seen from figure 10-32, the com- er unit is the "heart" of the ground posi- n indicator (GPI) system. For detailed ormation on computers, refer to NavPers 88, Digital Computer Basics; only the block gram of the particular application will be cussed in this chapter.

The airborne dead-reckoning computer con- uously determines ground position from an ial starting point. All of the information essary for its operation is contained within aircraft. The necessary data to operate computer are (1) magnetic heading of the craft, supplied by the magnetic compass; airspeed, supplied by the pitot pressure; local magnetic variation, which is manually erted to change magnetic heading to true ding; and (4) windspeed and wind direction, ich are also manually inserted.

speed Channel

In performing its operations, the computer siders true airspeed, true heading, and e. The resolvers in the computer are circuits designed to break up a vectorial quantity into two components. The outputs are the sine and cosine values of the quantity. The airspeed channel receives information from the pitot pressure and resolves this information into true airspeed. The servomotor then positions the N/S and E/W potentiometers in the heading channel to a value that represents true airspeed.

Heading Channel

Magnetic heading obtained from the aircraft's compass system is corrected to true heading in the heading channel. Voltages proportional to the directional components (N/S and E/W) of true heading, derived from a sine-cosine resolver, are applied to the dual sections of the airspeed potentiometers. The shaft of this potentiometer is positioned by the output of the airspeed channel. As a result, the output voltage of one section is proportional to the N/S component of airspeed, while the output voltage of the second section is proportional to the E/W components of airspeed.

Wind Channel

Up to this point the computer has determined and combined true airspeed and true heading, and has developed outputs that are the sine and cosine of the vector addition. In order to determine groundspeed, it is necessary to insert the direction and speed of the wind. Wind data may be obtained by any of several methods, including aerology and drift sights. These two factors (speed and direction) are inserted into the wind channel manually, and the resolver's outputs energize the N/S and E/W sections of the wind potentiometer.

Summing Network

The two inputs to each summing network are the components necessary to determine groundspeed. The inputs are derived from true heading, true airspeed, and wind data readings. The N/S summing network receives the cosine outputs from the heading and wind channels. The E/W summing network receives the sine outputs. In the N/S summing network, the N/S components of airspeed and wind are combined, and the result is an output voltage equivalent to the N/S groundspeed of the aircraft. Similarly, the E/W summing network has an output voltage equal to the E/W speed of the aircraft. The N/S and E/W channels are identical from this point on.

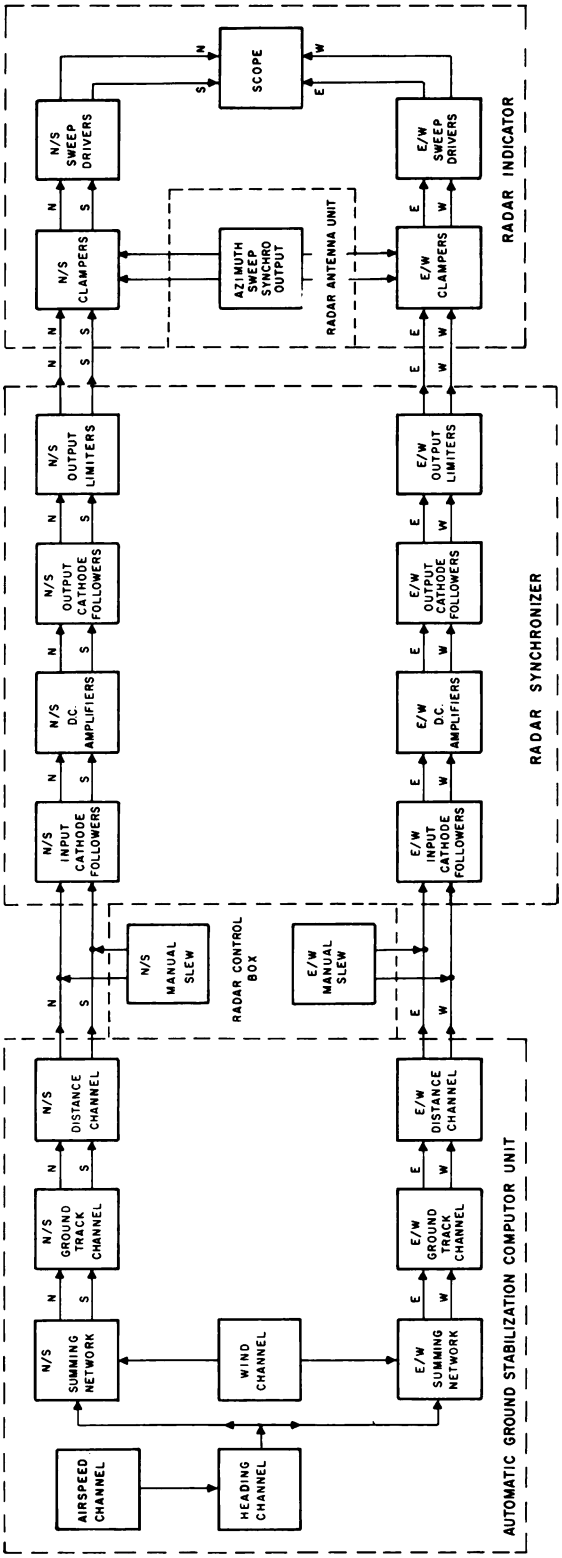

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Figure 10-32.—Ground position indicator stabilization system, block diagram.

After groundspeed has been determined, adding the factor of time is the only remaining factor in order to compute distance. This is done in the ground track channels, and both channels operate in exactly the same manner with their respective voltage inputs.

Ground Track Channel

The ground track channel converts the component of groundspeed into distance by taking into account the length of time the aircraft travels at the groundspeed. This is done by a motor-driven tachometer (or rate generator) which rotates at a speed proportional to the groundspeed of the aircraft. This rotation is in a direction corresponding to the direction of travel. A ground track synchro, coupled to the motor-generator, provides output data at 2 miles per revolution.

Distance Channel

The distance channels convert the rotation of the ground track synchros into distance counter information. By using synchros and servomotors, the information is transferred through a gearing mechanism that causes the stabilization potentiometers to provide the proper voltages to the radar sweep deflection system. These voltages (from the N/S and E/W stabilization pots) will ground stabilize the display so that the radar continues to view the area selected. The distance channel also positions the dials of the Veeder-root counter to indicate the distances traveled. Some computers will ground stabilize a sweep up to 300 miles. Beyond this range, resetting is required, resulting in the PPI origin being moved to a new position.

RADAR SECTION

The computer section is an auxiliary unit that works in conjunction with the radar set and the remaining GPI circuitry is self contained within the radar set.

The internal slewing circuits are identical for both manual and automatic operation. The amount of slew available for manual slew is 50 miles maximum in any one quadrant, and for automatic slew is 150 miles maximum in any one quadrant.

The manual slew helipots are located on the control box. Only N/S circuitry is discussed because the E/W circuitry is identical. Figure 10-33 is a simplified schematic and presents only that portion of the circuitry that pertains to the slewing function.

The synchronizer provides the circuitry necessary to convert the input voltages into the push-pull d-c output voltages necessary for slew indications. This conversion is accomplished by the following four main stages:

1. Input limiters—which provide the safety factor for the input cathode followers and d-c amplifiers.
2. Input cathode followers—which isolate the input circuits from the d-c amplifiers.
3. D-c amplifiers—which are used in conjunction with their degenerative feedback loop to control the gain.
4. Output cathode followers—which are used to isolate the d-c amplifiers from the indicator circuits and to provide degenerative feedback for the amplifiers.

In the indicator section, the sweep voltages are combined with the slew voltages. The clampers in the indicator section are controlled by the sweep and slew voltages and in turn provide the proper bias for the sweep drivers. The drivers provide the proper sweep currents for the deflection coils.

Circuit Analysis

In order to determine the position of the origin of the sweep on the indicator, the bias on the sweep drivers must be controlled. When it is desired that the sweep origin be in the center of the indicator, all four drivers are held at -19 volts d-c grid bias. Whenever slew is desired, this bias is changed in a push-pull manner in the direction desired. Helipots (R1 and R2) provide the manual slew input for the N/S channels. A maximum of 50 volts push-pull may be obtained from the two ganged controls. One volt, at this point, provides 1 mile of slew (displacement) on the indicator.

INPUT CATHODE FOLLOWER.—The input cathode-follower circuit is for the north and south d-c amplifiers, V902 and V903, respectively. The input cathode follower, V905, is a duotriode. The north and south reference voltages from the ground stabilization computer vary at the rate of 1 volt per mile in relation to the movement of the aircraft with respect to a point on the ground. These varying voltages are applied, through voltage dividers comprised of resistors R15 and R293 and R11 with

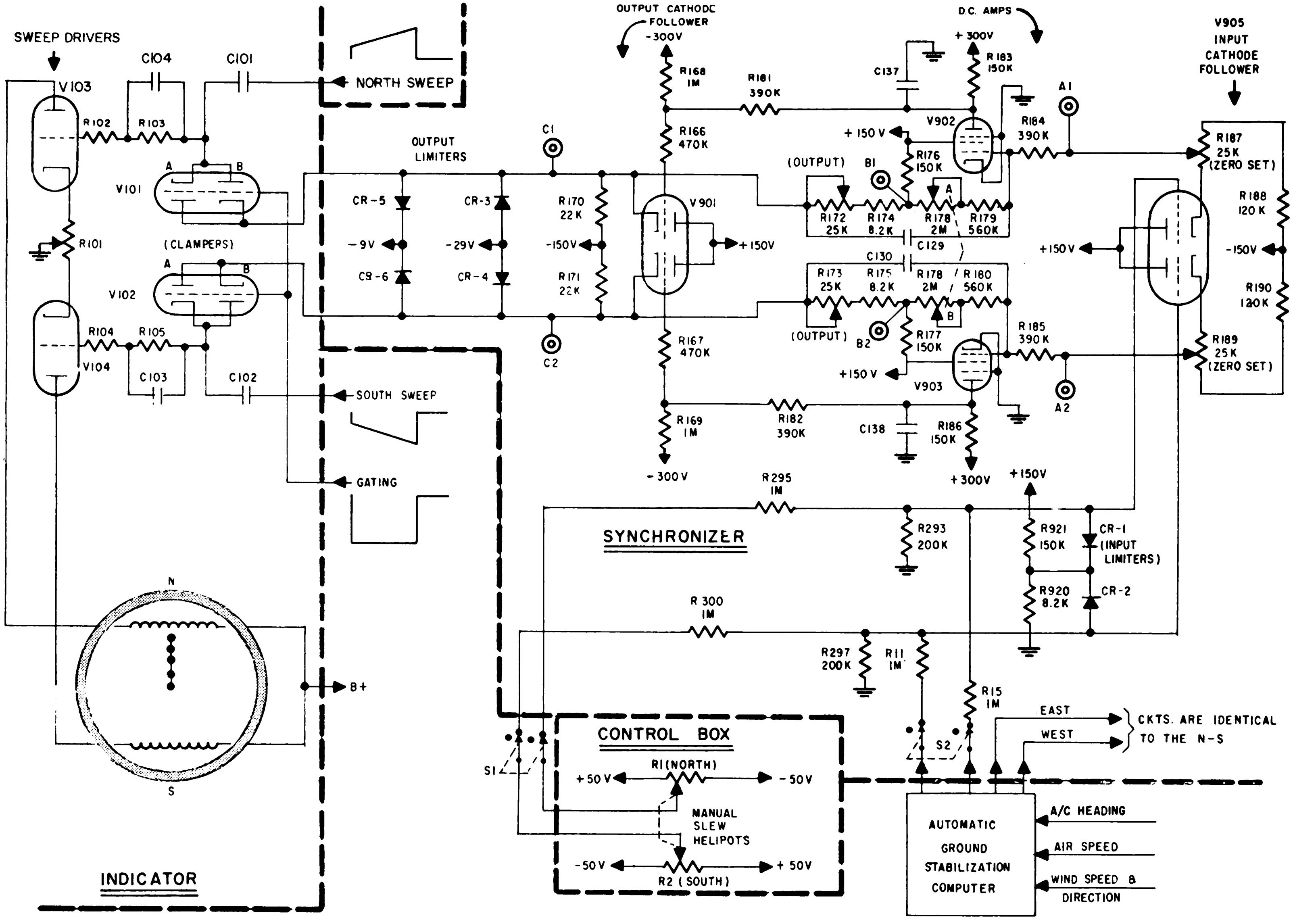


Figure 10-33.—GPI schematic (radar section).

R297, to the appropriate grids of V905. These changes in voltage slew (move) the origin of the sweeps, which represent the position of the aircraft, in the same direction in which the aircraft is flying and a distance indicative of its change in position measured in miles.

The other slewing voltages are applied through similar voltage dividers, composed of resistors R295, with R293 and R300 with R297, to the grids of V905. These voltages are supplied from the control box by manually adjusting the N/S slew control (R1 and R2) and are combined with the slewing voltage from the ground stabilization computer at the grids of V905. The automatic function of the slewing voltages from the ground stabilization computer is not affected; but by means of the local slewing voltages, the origin of the sweeps can be moved in any direction, so that the desired portion of the sweep can be brought into view and the target centered on the indicator. By means of relays and different voltage dividers in the input to V905, the indicator sweep range may be changed without affecting the ground stabilized presentation on the indicator. With the proper resistance values selected, after the target has been slewed to the center of the indicator, it will remain there even though the range is changed.

By means of slew switch S1, the manual slewing voltages can be cut in or out of the circuit; and with the ground GPI switch S2, the slewing voltages from the ground stabilization computer can be cut in or out. Therefore, by opening or closing these switches separately or together, either or both slewing voltages can be cut in or out of the circuit. If both are cut out of the circuit by opening both switches, the voltages on the grids of V905 are balanced. This gives a PPI presentation in which the start of the sweep is centered on the indicator screen.

The two silicon diodes, CR1 and CR2, are employed as limiters to prevent either grid of V905 from going more positive than 7.8 volts. This avoids the possibility of damaging this tube, the d-c amplifier, and other tubes in associated circuits. A voltage divider comprised of R921 and R920 maintains the negative sides of the silicon diodes (CR1 and CR2) at a positive potential of 7.8 volts.

The cathodes of V905 are connected to -150 volts through resistors R187 with R188 and R189 with R190. The outputs from the cathode followers are taken from R187 and R189.

D-C AMPLIFIER.—With each input cathode follower are associated two d-c amplifiers. A pentode type tube is used in each d-c amplifier stage. The amplifier fed by the north section of the input cathode follower, V905, amplifies the north d-c input slewing voltage and provides a north-slewing voltage for the indicator. The north d-c amplifiers and its complement, the south d-c amplifier, effectively form a push-pull circuit which affects the north-south sweep in the indicator. Since all of these amplifiers are identical, only one will be discussed.

The north output of the input cathode follower is applied through variable resistor R187 and fixed resistor R184 to the grid of the d-c amplifier tube, V902. The variable resistor N ZERO SET is adjusted, with all input slewing voltages at zero (slew switch off and GPI switch off), until the north d-c amplifier is operating at the proper quiescent level for centered presentation. Resistors R170, R172, R174, and R176 form a voltage-divider network between a + 150 volts d-c and a -150 volts d-c. The N/S gain control, R178A, adjusts the d-c feedback from the output cathode follower through the series resistors R172, R174, R178A, and R179 to the grid of the d-c amplifier, V902, thereby controlling the gain of the amplifier. This gain control is ganged to a similar control, R178B, for the south d-c amplifier, V903, so that the gain of these complementary stages is always the same. Variable resistor R172, N OUTPUT, adjusts the output voltage to obtain the proper bias on the sweep driver stages in the indicator. This bias voltage can be measured at test jack C1 and in a static state (no slew applied) is -19 volts d-c.

OUTPUT CATHODE FOLLOWER.—Since the output of the d-c amplifier is applied to a low-impedance input in the sweep amplifier, the d-c amplifier is coupled through a cathode-follower stage. A duotriode tube is used, and each section functions as a cathode follower for one d-c amplifier. The output of the north d-c amplifier, V902, is applied through resistors R181 and R166 to the grid of one section of the cathode-follower tube V901, and the output of the complementary south d-c amplifier is applied to the other section of V901. The resistor network, composed of resistors R183, R181, and R168, forms a voltage divider to obtain the proper plate voltage for the d-c amplifier and, together with resistor R166, determines a fixed bias for the output cathode follower. Capacitor C129 provides a low-impedance path for any a-c ripple which may be present from the cathode of the output cathode follower back to the grid of the d-c amplifier. This feedback greatly attenuates any a-c ripple and prevents "jitter" of the presentation on the indicator.

The output is taken from the cathode of V901 (north), and is used to establish the bias on the north sweep driver. Similar outputs from the other output d-c amplifiers establishes the bias on the south, east, and west sweep drivers for the indicator. By varying these bias voltages, the start of the sweep on the indicator can be changed as desired, or as dictated by the position of the aircraft.

OUTPUT LIMITER.—In order to limit, at the proper peak and minimum values, the slewing bias from the output cathode follower, two parallel diode limiters are used. Four silicon diodes are employed with two in the north d-c amplifier circuit and two in the south d-c amplifier circuit. A potential of approximately -9 volts is applied to the negative sides of CR5 and CR6 by a voltage divider. A potential of approximately -29 volts is applied to the positive sides of CR3 and CR 4 by another voltage divider. The double limiting provided by these circuits limits the available slew range to approximately 2 radii at the output and, in addition, protects the sweep drivers in the indicator from being overdriven by limiting their bias to a range from -9 volts d.c. to a -29 volts d.c. The output limiters, along with a maximum local slewing voltage of ±50 volts and a maximum ground stabilization slewing voltage of ±150 volts, determine the overall slewing ranges of the indicator.

SWEEP DRIVER AND CLAMPER.—There are four identical sweep-driver circuits in the indicator. Each sweep-driver circuit affects one phase of the sweep; that is, either north, south, east, or west. The sweep voltages from the sweep synchro in the antenna are passed directly into the indicator. These voltages are applied to the sweep-driver stages for amplification prior to being coupled to the appropriate deflection coil of the indicator. Since all the circuits are identical, only one circuit will be discussed.

A phase of sweep input is fed through C101 to the "A" cathode and the "B" plate of V101, a duotriode operated as a two-way clamper, and through C104 to the grid of the sweep driver, V103. The negative-going clamp-gate square wave is applied to the grids of the duo-clamper. The duration of the negative half cycle of this square wave is equal in time to the duration of the sweep sawtooth waveform. The slew voltage is applied to the "A" plate and the "B" cathode of V101. Since the clamp-gate and sweep waveforms are equal in duration, application of the clamp-gate waveform to the clamp tube, V101, cuts it off and allows the sweep voltage waveform to be felt on the grid of the sweep driver, V103, and varies its conduction. During the blanking time of the sweep, the clamp action (known as synchronized clamping) is such that the grid of the sweep driver is clamped to a desired slew potential, to insure the proper starting point of the sweep. This desired slew potential determines the quiescent plate current in the driver tube, and thus controls the starting point of the sweep seen on the indicator. In this manner, the origin of the sweep can be moved or slewed on the indicator to view any portion of the sweep. If the bias on the sweep driver is made less negative, more current will flow through its associated section of the yoke. Therefore, the origin will move in the direction and distance represented by the amplitude of the output of the sweep driver; R101 is the N/S centering adjustment for the indicator.

CHAPTER 11

AIRBORNE DOPPLER NAVIGATION

DOPPLER PRINCIPLE

The Doppler principle involves the effect of motion on a wave which has been generated and propagated. This effect is based on the fact that all waves, once they have been propagated into space or into a conducting medium, travel at a velocity which is independent of the wave source. The effect was first noted in connection with sound waves; it has subsequently been observed throughout the entire frequency spectrum. In all cases, a shift in the apparent frequency occurs when the wave source and the detector move toward or away from each other. If the distance separating the source and the detector remains constant, no frequency shift occurs. The present discussion is limited to the implications of this principle in electronic applications.

PRINCIPLE

For this discussion, assume that a wave source is moving in the direction of its propagation. As the source moves, it partially overtakes one wave front before the next is emitted. This has the apparent effect of decreasing the distance between corresponding points on successive waves. (The speed of wave travel is independent of the motion of the source, and need not be considered in the discussion.) The wavelength (as the waves reach a stationary detector located ahead of the source) is shorter than the original frequency would indicate; the detector apparently receives a frequency higher than that propagated. If the source moves in a direction opposite to the direction of propagation, the frequency is decreased in a corresponding manner.

The same effect is noted in the case of a stationary source and a moving detector. In this case, the detector is overtaking part of the wave front, and the time and wavelengths are shortened, and the frequency is apparently increased.

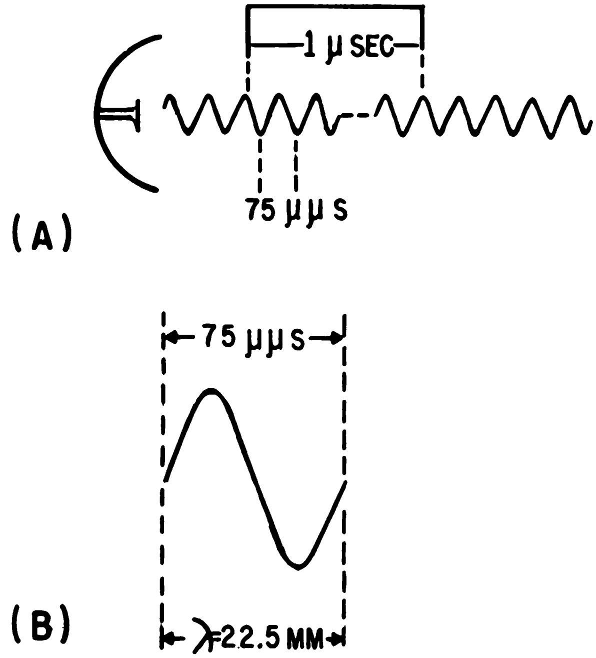
THEORY

This discussion of the Doppler principle is somewhat simplified in order to present the fundamental theory involved. In the explanation that follows, three aspects of a given radar beam are discussed. These are the generated signal wave, the incident wave, and the received wave. The timing of the wave is discussed and illustrated to show how phase shift and frequency shift occur.

An examination of one microsecond of the signal radiated from a CW radar transmitter shows that the signal is composed of many cycles of RF energy. In the time of 1 microsecond, a radar that operates at 13.3 GHz will radiate 13,300 cycles of RF energy, only a few of which are shown in figure 11-1 (A). Each cycle occupies a definite period of time and has a definite physical wavelength. At the frequency mentioned, each cycle occupies 75 micromicroseconds and has a physical wavelength of 22.5 millimeters. An expanded view of one cycle of RF energy at 13.3 GHz is shown in (B) of the figure. This cycle will later be shown with one cycle of incident signal superimposed on it to demonstrate expansion due to Doppler effect.

At this point two approaches to explain the effect of signal expansion are used; one involves the action of a cycle of energy as it leaves the antenna, and the other considers the shape of each cycle to be an arc of wave energy. First, consider a single cycle as it leaves the antenna.

The cycle shown in figure 11-1 (B) occupies a certain discrete distance in space and is, in fact, the wavelength of the signal at the frequency shown. When transmitted from a stationary antenna, the leading edge will move out into space 22.5 millimeters by the time the trailing edge leaves the antenna. However, if that cycle is emitted from an antenna pointed aft from a moving aircraft, then the antenna will move a small distance during the time that the cycle is being



AT.147

Figure 11-1.—Examination of a pulse.

transmitted. The trailing edge will, therefore, be a greater distance away from the leading edge than it was when the cycle was transmitted from the stationary antenna. This is expansion.

Figure 11-2 illustrates this effect and shows, by the dotted line, the space that a cycle would have occupied had the antenna been stationary. Inasmuch as the cycle has been expanded, it occupies more distance in space, the wavelength has been increased, and the frequency has been proportionately decreased. The difference in frequency for this first Doppler shift is proportional to the sine of the radar beam angle multiplied by the ratio of the aircraft velocity to the generated wavelength. In symbols, this would be

$$D.s. = \frac{V}{\lambda} \times \sin \phi$$

When the signal is reflected from the ground and returns to the antenna, a similar expansion occurs. A slightly longer time is required for the cycle to reenter the moving antenna than that would be required if the antenna were stationary. Thus, a double expansion has occurred. This double frequency expansion can be measured by the formula.

$$D.s = \frac{2V}{\lambda} \times \sin \phi$$

The change in frequency is slight, but measurable, and is a direct indication of the speed of the aircraft.

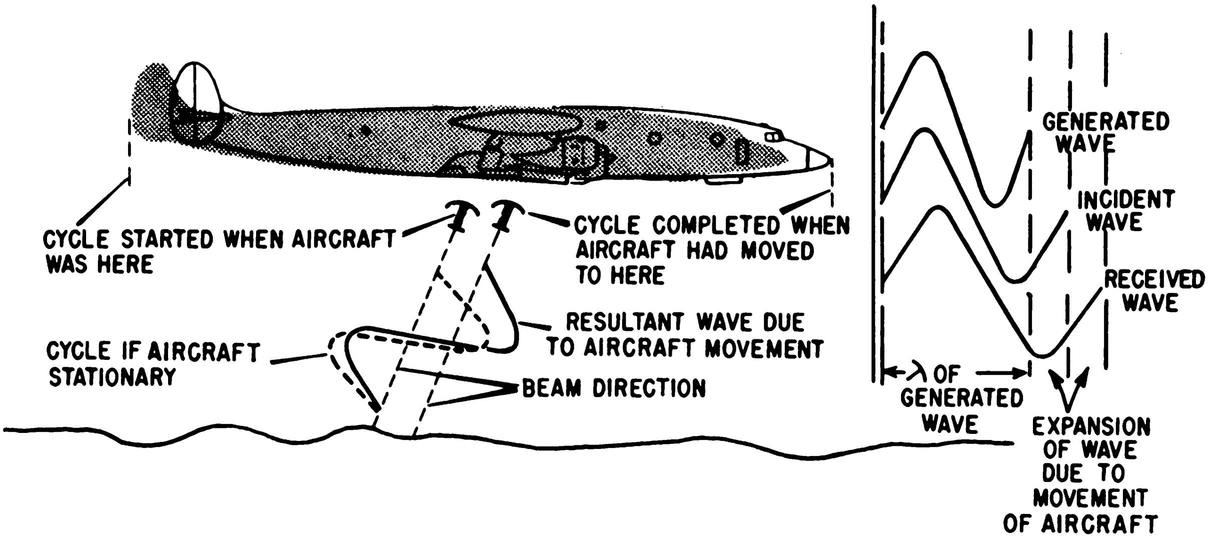
Compression of the signal will result if the antenna is pointed in the forward direction. The explanation is similar to that of expansion except that the leading and trailing edges of the cycle will be closer together (cycle compressed). The effect will be to shorten the wavelength and increase the frequency.

Another approach to compression and expansion is to consider that a CW signal consists of waves of energy radiated from the antenna. Figure 11-3 illustrates the spacing between the waves of a signal from both stationary and moving antennas. The effect is the same as that previously described. The increased spacing (wavelength) between adjacent waves of energy is a direct indication of frequency change. The received signal frequency, when mixed with the generated signal frequency, produces a difference frequency which falls in the audio spectrum. This audiofrequency is a direct indication of the aircraft's speed.

DOPPLER NAVIGATION SYSTEMS

Doppler navigation radar automatically and continuously computes and displays groundspeed and drift angle of an aircraft in flight without the aid of ground stations, wind estimates, or true airspeed data. This is done by utilizing auxiliary inputs from an altitude rate sensor and from the aircraft's vertical reference system. Doppler navigation radars do not sense range and bearing (direction) as ordinary search radars do. They employ continuous carrier or pulse transmission energy and determine the forward and lateral velocity components of the aircraft by utilizing the apparent frequency change phenomenon (Doppler shift) in the RF range.

The radar radiates CW or pulsed energy (depending on the type of system being used) at one RF frequency and the radiated energy is beamed fore-aft and left-right of the aircraft; these beams of energy strike the earth's surface and are reflected. Energy waves returning appear to be spaced differently than the waves that were transmitted.


CYCLE STARTED WHEN AIRCRAFT WAS HERE
CYCLE COMPLETED WHEN AIRCRAFT HAD MOVED TO HERE
RESULTANT WAVE DUE TO AIRCRAFT MOVEMENT
CYCLE IF AIRCRAFT STATIONARY
BEAM DIRECTION
GENERATED WAVE
INCIDENT WAVE
RECEIVED WAVE
λ OF GENERATED WAVE
EXPANSION OF WAVE DUE TO MOVEMENT OF AIRCRAFT

AT.148

Figure 11-2.—One cycle expansion.

The receiver of the Doppler radar system detects this apparent change in frequency; this is accomplished by use of two signal inputs—one from the transmitter and one from the receiver antenna. The input signal from the transmitter is at all times the same frequency as the signal being radiated; the receiver antenna signal frequency will vary with the forward and lateral velocity of the aircraft. The two frequencies are compared in the receiver, and the difference frequency is representative of the groundspeed and drift angle of the aircraft.

FIXED-WING SYSTEM (AN/APN-153)

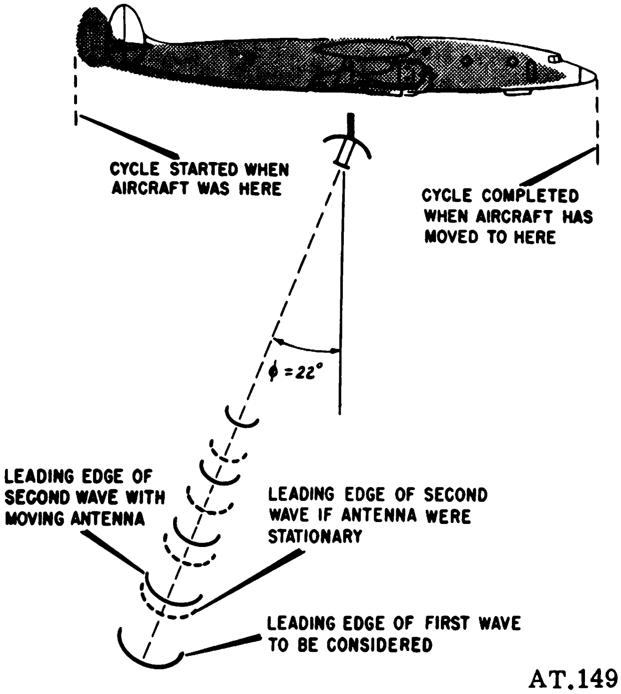
The AN/APN-153(V) is a lightweight, miniaturized groundspeed and drift angle measuring system which is designed to satisfy the navigational requirements of modern military fixed-wing aircraft. It uses Doppler pulsed radar techniques to measure groundspeed and drift angle directly, continuously, and accurately. It operates anywhere, is relatively unaffected by weather conditions, and is independent of ground-based navigational aids. Its small size and light weight permit it to be easily installed in almost any fixed-wing aircraft.

The radar's groundspeed and drift-angle data, together with aircraft heading data from any standard compass, are used to compute an aircraft's track projected on the ground. Using this information and conventional dead reckoning techniques, a pilot can navigate accurately over long distances.

Application

Groundspeed and drift data, in addition to being presented on a counter and dial, are available as electrical outputs. These outputs can be fed automatically and continuously to navigational computers, mapping cameras, search radars, or other equipment which ordinarily utilize manual inputs of equivalent information.

A particularly useful application of the AN/APN-153(V) is its interconnection with various dead reckoning navigational computers, such as the AN/ASA-13A. Without the aid of a groundspeed and drift-angle measuring system, navigational computers are sharply limited by the accuracy of the input information. The input data may consist of windspeed and direction, true airspeed, and aircraft heading. Only aircraft


CYCLE STARTED WHEN AIRCRAFT WAS HERE
CYCLE COMPLETED WHEN AIRCRAFT HAS MOVED TO HERE
$\phi = 22°$
LEADING EDGE OF SECOND WAVE WITH MOVING ANTENNA
LEADING EDGE OF SECOND WAVE IF ANTENNA WERE STATIONARY
LEADING EDGE OF FIRST WAVE TO BE CONSIDERED

AT.149

Figure 11-3.—Energy wave spacing.

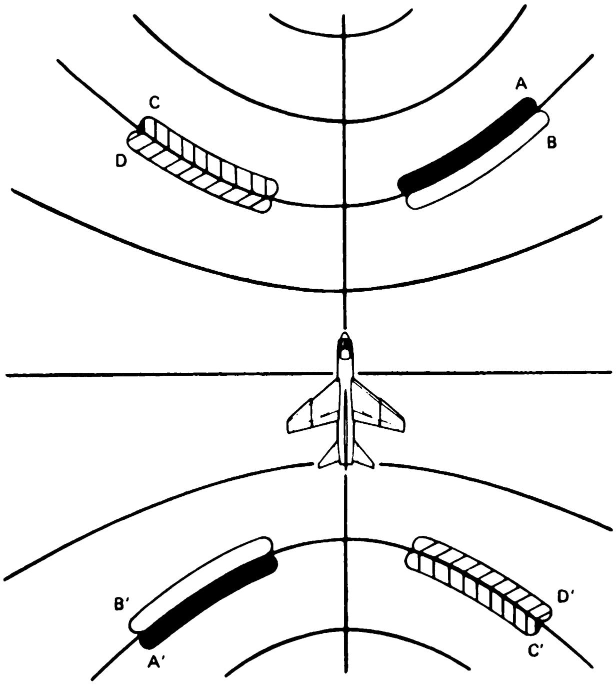
heading is usually obtainable with any high degree of accuracy.

Interconnection with this type of computer provides an automatic-navigator which presents the aircraft's position with extreme accuracy. It is not limited by the accuracy of either available wind information or true airspeed data. The groundspeed and the drift angle are measured data and include the effect of wind. Thus, during normal operation, groundspeed and drift angle data need only be supplemented by aircraft heading data for continuous and automatic computation of the aircraft's position (given certain initial conditions).

Operating Principles

The AN/APN-153(V) emits short pulses of microwave energy, so the transmitter is not operative while an echo is being received. Therefore, in a single-beam radiation pattern there would be no second frequency with which to compare the echo. However, two beams—one projected dead ahead and the other directly behind—would experience equal but opposite Doppler shifts. In this event, one-half the difference between the two echo frequencies is the Doppler shift of either beam, and is proportional to groundspeed. This condition assumes no drift. If drift were present, the two-beam system described above would not detect it when used with pulsed beams. Antennas radiating to the left and right would detect sideways motion, but not fore and aft motion.

In order to make simultaneous measurement of both groundspeed and drift angle, the AN/APN-153(V) uses a modification of the two-beam pattern. The vicinity of the aircraft is divided into four quadrants—left forward, left rearward, right rearward, and right forward. (See fig. 11-4 (A)). Simultaneous beams are radiated into diagonal quadrants, with switching of the quadrants at regular intervals.



AT.539

Figure 11-4.—Four-beam pattern, using two-beam transmission.

When there is no drift, the ground track and aircraft heading coincide. In this condition, as shown in (B) of figure 11-4, the radiation pattern is symmetrical about the axes of the aircraft, and the left and right beams are at the same angle from ground track. The Doppler shift is equal in the beams.

When the antenna is not alined with ground track (fig. 11-4 (C)), an angle exists between the antenna axis and ground track, and the beams experience unequal shifts. The difference frequency resulting from one pair of beams is higher than that from the other. As the switching action occurs, this difference is processed as an error signal which, through servo action, drives the antenna into alinement with ground track.

When the antenna is alined with ground track, the angle between the antenna axis and the aircraft heading represents the drift angle. Through a synchro system, this information is supplied to the computer along with the groundspeed data.

Advantages and Disadvantages

Due to its special radiation pattern, the AN/APN-153(V) is not affected by the vertical component of velocity which occurs during ascending or descending flight. Changes of altitude affect each beam equally, so the difference frequency remains the same. It is the difference frequency which is utilized to represent velocity.

Small roll and pitch angles of the antenna exist during normal flight. Roll angles introduce a greater shift into one beam and a smaller shift into the other, but the difference frequency is changed only slightly. Therefore, the inaccuracy of groundspeed measurements resulting from roll variations is very slight. Pitch angles do, however, cause inaccuracies which are significant. Therefore, the antenna is stabliized in its pitch axis to minimize pitch errors.

IGHT-BEAM SYSTEM
(AN/APN-190(V))

The Doppler Radar Navigation Set AN/APN-190(V) is an airborne groundspeed and drift-angle measuring system using the Doppler principle to extract data from reflected signals. A lightweight system operating on a frequency of 13.325 (±0.05) GHz, it precisely measures, processes, and indicates groundspeed and drift-angle information aboard aircraft. The APN-190(V) is essentially a solid state system of high operational reliability that requires minimum maintenance. It is used in conjunction with a navigation/weapon delivery computer, inertial measurement system and a heads-up display set; it operates continuously anywhere in the world, is independent of ground-based navigational aids, visibility, and weather conditions, and has a self-testing capability.

In measuring the groundspeed and drift angle of a fixed-wing, in-flight aircraft, the system transmits narrow beams of electromagnetic energy downward from an antenna stabilized in pitch, roll, and azimuth to illuminate small areas on the earth's surface. A portion of the transmitted energy reflected from the surface is received and processed by the system to determine the Doppler frequency shift.

Operating Principles

The AN/APN-190(V) radiates a four-beam pattern consisting of two beam-pairs alternately switched from left to right of the aircraft fore-aft axis. Frequency shifts occurring in each beam are proportional to the components of aircraft forward and lateral velocity along the respective antenna beam. The frequency shifts, which are due to the Doppler effect, are detected by mixing a portion of the transmitted signal with the received signal and detecting the audio beat frequency.

After detection, the Doppler signals are fed to groundspeed and azimuth tracking circuits; these circuits convert the signals into voltages proportional to groundspeed and azimuth. Outputs proportional to these voltages are provided in proper electrical form to drive the appropriate auxiliary equipment.

Equipment Theory

The magnetron in the radar transmitter generates 200-volt pulses of RF energy at a PRF of 80-120 kHz with an average power of 10 watts. The magnetron output is applied to a crystal switch which passes the magnetron pulses to a duplexer to route the microwave energy to a waveguide assembly. During the transmit cycle, the receiver crystal switch is closed, thus minimizing coupling of the transmitted energy into the receiver. The duplexer permits the same antenna to be used for both transmitting and receiving and isolates the sensitive receiver from the transmitter. It also couples the transmitted signal to the waveguide assembly and, during the receive cycle, couples the return signal from the waveguide to the receiver switch. The waveguide couples transmitter RF energy to the antenna. Four radiating elements composed of a K-band waveguide, four reflectors, and a waveguide flange complete the antenna array.

When transmitting, the generated RF energy is applied through the crystal switch to the duplexer and waveguide assembly, coupling the energy to the antenna so that the switching and array combination generates eight beams of energy (fig. 11-5) radiated two at a time in the following order: front right (A) and aft left outer (A'); front right (B) and aft left inner (B'); front left (C) and aft left outer (C'); front left (D) and aft right inner (D'). Left-right switching and fore-aft beam lobing are caused by coded signals supplied by the receiver-transmitter to the switching modules in the antenna assembly.

The antenna is stabilized in pitch and roll to compensate for changes in aircraft attitude. Pitch and roll stabilization is achieved by means of servo loops which receive pitch and roll attitude signals from a pitch and roll reference input. Servomotors drive the antenna array pitch and roll gimbals through their respective gear trains. The array is also driven in azimuth by a servo loop so that it is alined with the aircraft ground track to compensate for aircraft drift conditions up to 30°. During receive, the return signal is coupled from the antenna through switching modules, through the waveguide assembly to the duplexer, where it is then routed to a receiver switch.

The receiver accepts the Doppler return and processes it to provide output frequencies falling within a 1-kHz to 36-kHz band which contains both groundspeed and azimuth drift information. These output frequencies are applied to frequency tracking circuits, which consist of groundspeed tracking and azimuth tracking loops; the ground tracking circuits measure Doppler frequency and provide an analog groundspeed output; the azimuth tracking loops compare the Doppler shift of two transversely switched beam-pair returns and drive the antenna in azimuth until it is alined with the ground track, at which time Doppler shifts from both beams are equal. As a result, the angle between antenna fore-aft and aircraft axes is equal to azimuth drift angle. A potentiometer positioned by an antenna azimuth drive shaft provides an electrical analog output of drift angle to analog-to-frequency conversion circuits. Frequency-to-digital conversion circuits using input frequencies representing groundspeed and drift angle provide a 60-bit data word representing groundspeed, drift angle, and system status for use by digital navigation computers and in inertial system correction.

ROTARY-WING SYSTEM (AN/APN-130(V))

The AN/APN-130(V) is a four-beam navigation set which provides information for use in helicopter automatic navigation, as well as control during hovering and directional flight. This equipment is a representative advanced Doppler equipment used for measuring ground velocity components of helicopters and other air vehicles having hovering and negative speed capabilities. The set incorporates an antenna design featuring narrow beam widths, low sea effect errors, fully automatic navigate-hover transition, and automatic frequency trackers.

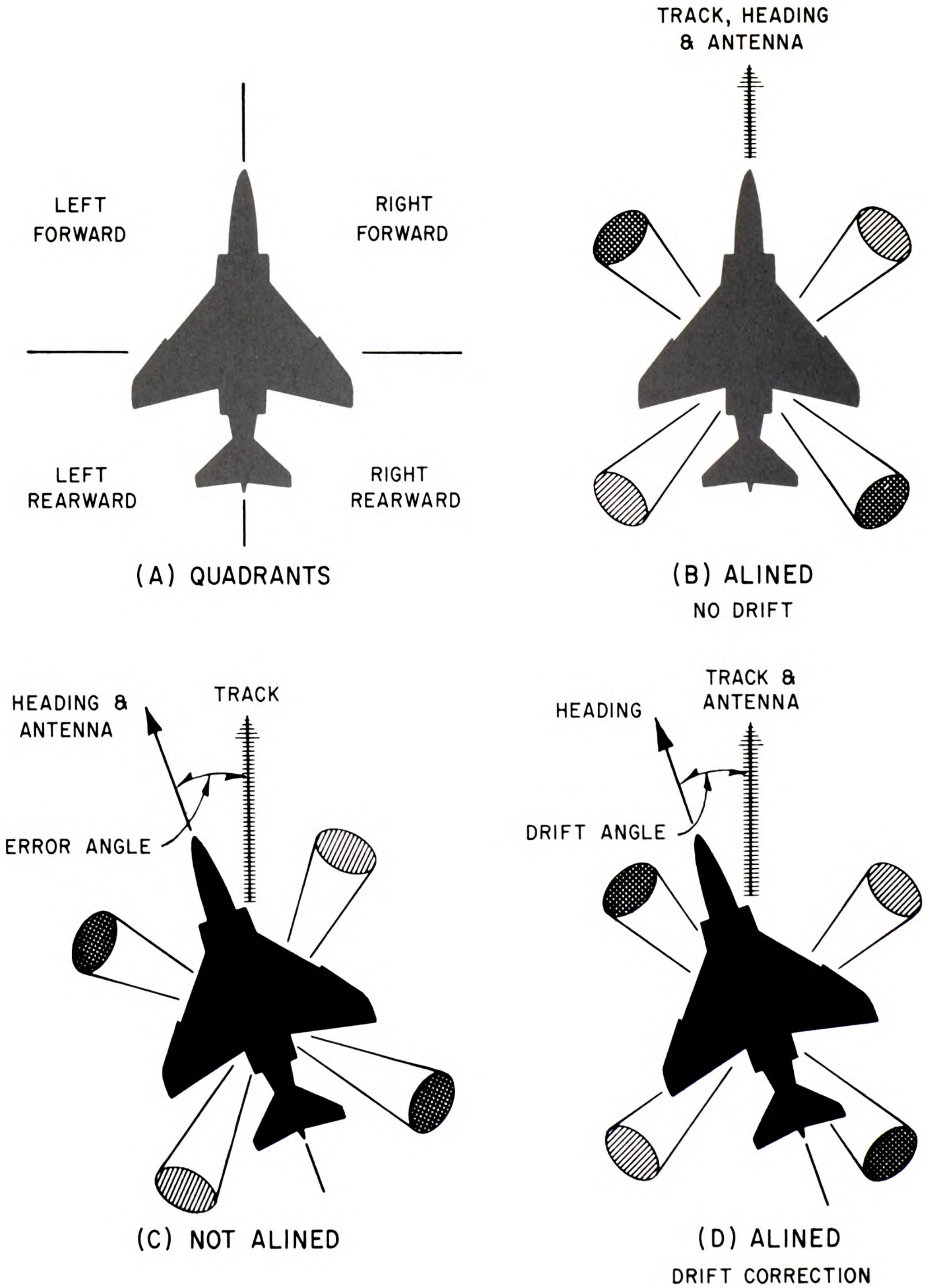
Operating Principles

The set employs four narrow beams of continuous-wave energy directed downward and outward, fore and aft, and in symmetrical configuration with respect to the aircraft, as shown in figure 11-6. Frequency shifts occurring in each beam are proportional to the components of aircraft velocity along the respective antenna beam. The frequency shifts, which are due to the Doppler effect, are detected by mixing a portion of the transmitting signal with the received signal and detecting the audio beat frequency.

After detection, the continuous Doppler audio signals are amplified and supplied to the signal data converter which converts the signals into voltages proportional to the aircraft heading velocity, drift velocity and vertical velocity. Outputs proportional to these voltages are provided in proper electrical form to drive the appropriate auxiliary equipment.

Equipment Theory

The klystron tube in the radar receiver-transmitter generates continuous-wave RF energy at a frequency of 13.3 GHz ± 5 MHz with a minimum power of 4.5 watts. The RF energy is coupled into the four transmitting wave guides and transmitted toward the earth in four narrow beams. A small portion of the



AT.331

Figure 11-5.—Antenna radiation pattern.

transmitted energy is coupled into each pair of receiving waveguides through directional coupling slots spaced (electrically) 180° apart. (See fig. 11-7.) A portion of the transmitted energy is reflected from the earth to a parabolic reflector and into the four receiving horns. The RF energy for each beam is divided and coupled into two receiving waveguides for each beam. At this point, the two received signals for each beam are designated A and B. The configuration of the A and B channel waveguides is such that the A signal is shifted 1/4 wavelength or 90° from the B signal. The eight received signals are heterodyned with the transmitted signal at the crystal detectors. The eight low-level Doppler signals are fed to the amplifiers where they are amplified to a sufficient level for transmission to the signal data converter.

Four pairs of signal channels in the signal data converter receive the corresponding pairs of quadrature signals from the audio amplifier subassemblies of the radar receiver-transmitter. Each pair of signal channels corresponds to one of the four antenna beams. (See fig. 11-8.)

The signal data converter provides two basic modes of operation-hover and navigate. Transition between these two modes is automatic when the HOV/AUTO switch on the control-indicator is in the AUTO position. In the HOV position, all channels of the signal data converter are locked in the HOVER mode of operation. In the AUTO position, each channel pair is switched to either the HOVER or the OMNIDIRECTIONAL NAVIGATE mode independently of the other channels, or all channels may be switched simultaneously to the FORWARD NAVIGATE mode. The switching is controlled by the signal-to-noise density ratio and the frequency of the Doppler signal in each channel. A fail-safe feature is provided wherein each channel is automatically switched from either of the navigate modes in the event that the Doppler signal is lost for a period exceeding approximately 2 seconds.

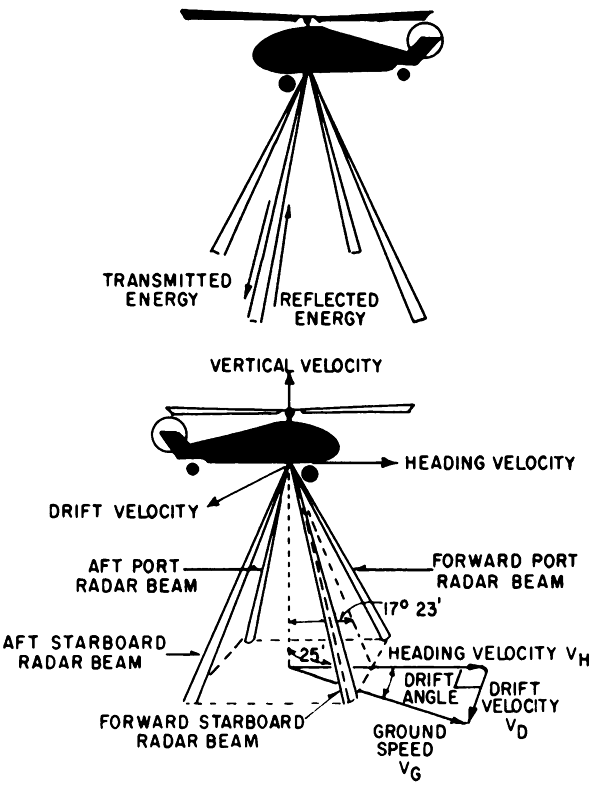


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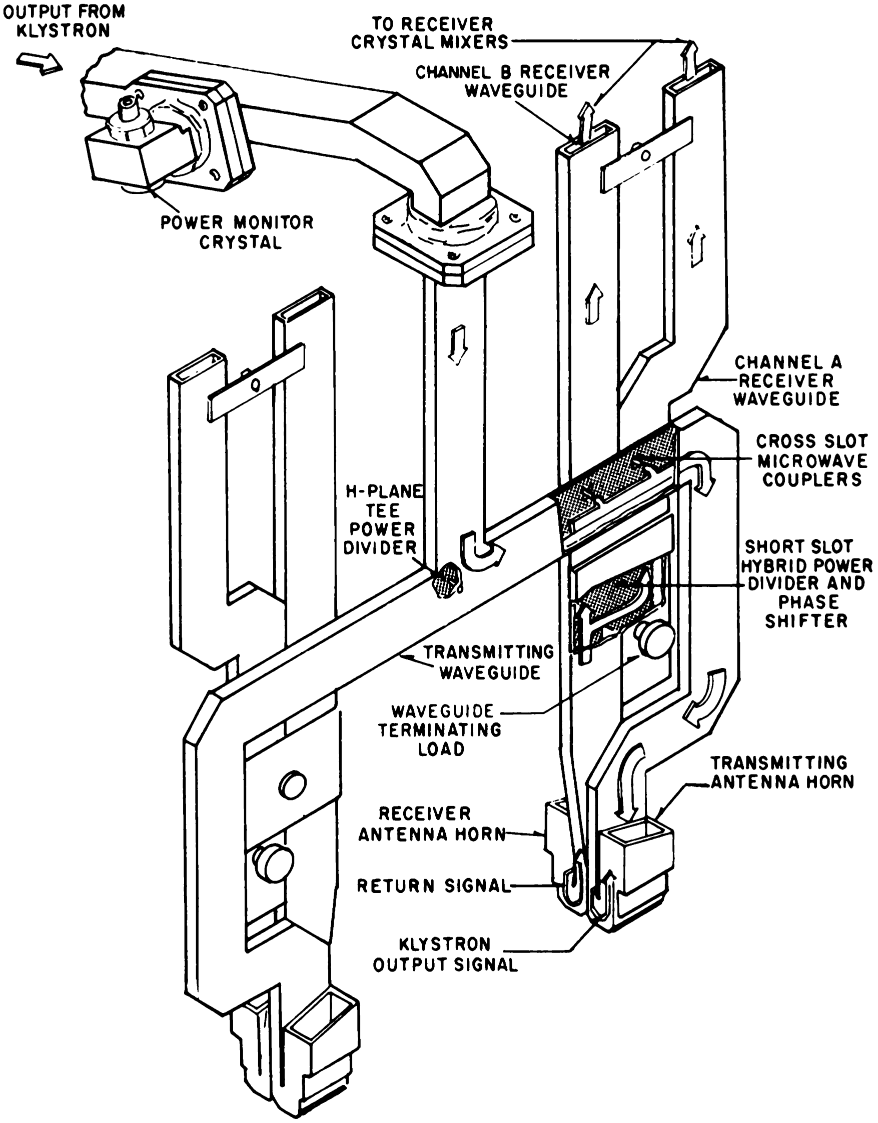
Figure 11-6.—Antenna beam orientation.

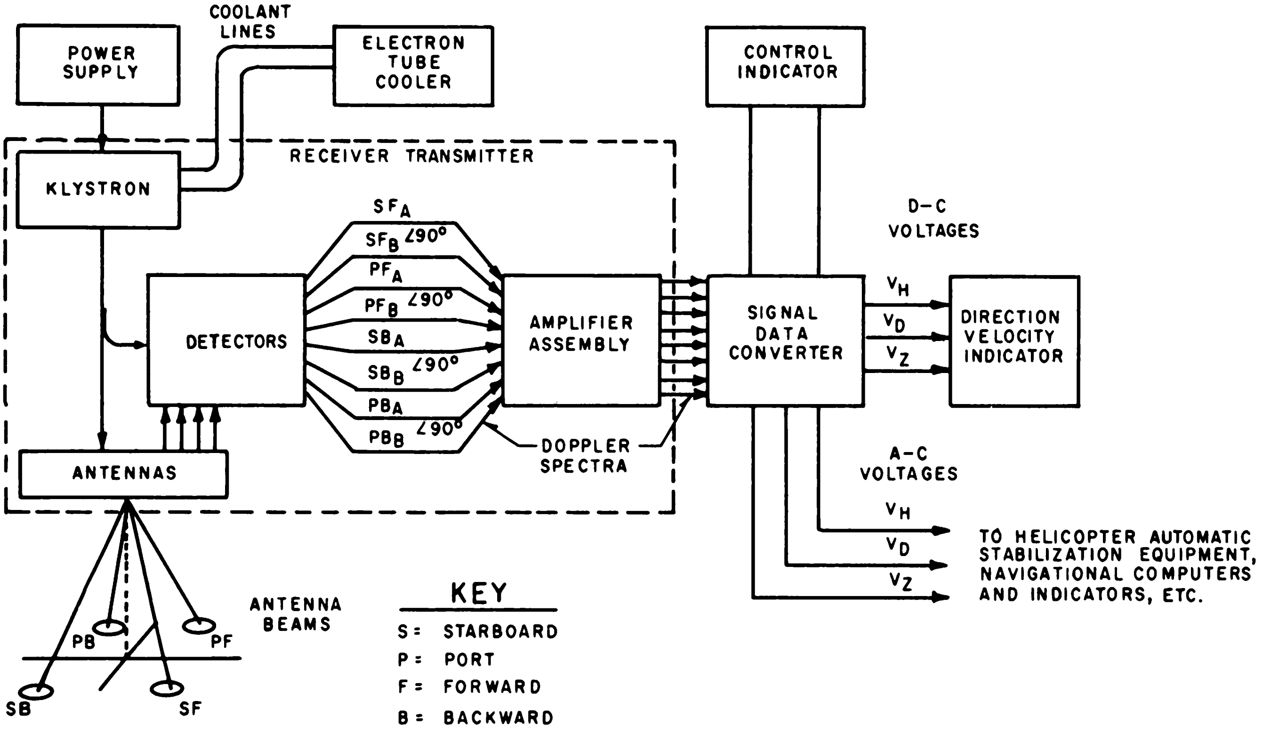
In fixed-wing aircraft, forward flight can be assumed. This is not logical in aircraft capable of negative velocities. Rapid direction sensing, as well as accurate velocity measurement, is extremely important for helicopter maneuvers at low velocities and during operations requiring hovering. The hover mode then requires coherent counting. Coherent counting, as used in this application, refers to the method used to develop an analog d-c output signal whose amplitude is proportional to aircraft velocity and whose polarity is an indication of aircraft direction. The Doppler signal in itself is not an indication of aircraft direction.

It is safe to assume that when a helicopter is traveling at some high rate of speed, the direction of flight is limited to forward flight with limited drift angle. Under these conditions, it is not necessary that each counter sense aircraft direction; therefore, the counters may operate in the noncoherent mode as long as the output polarities have been correctly established in velocity-sensing circuits.


OUTPUT FROM KLYSTRON
TO RECEIVER CRYSTAL MIXERS
CHANNEL B RECEIVER WAVEGUIDE
POWER MONITOR CRYSTAL
CHANNEL A RECEIVER WAVEGUIDE
CROSS SLOT MICROWAVE COUPLERS
H-PLANE TEE POWER DIVIDER
SHORT SLOT HYBRID POWER DIVIDER AND PHASE SHIFTER
TRANSMITTING WAVEGUIDE
WAVEGUIDE TERMINATING LOAD
TRANSMITTING ANTENNA HORN
RECEIVER ANTENNA HORN
RETURN SIGNAL
KLYSTRON OUTPUT SIGNAL

AT.333

Figure 11-7.—Waveguide subassembly, receiver-transmitter coupling.



AT.334

Figure 11-8.—Functional block diagram.

ASSOCIATED EQUIPMENT

As mentioned previously, Doppler navigational radar equipment by itself cannot determine aircraft position or navigate the aircraft to a predetermined point. However, when used with associated navigational computers, these operations can be accomplished. The major function of the Doppler equipment is to supply extremely accurate data concerning velocity and drift angle.

Although there are many airborne navigational computers in use at the present time (and more are being introduced each year), a brief discussion of the AN/ASA-13A and its plotting board OA-1768/ASA will illustrate the overall system.

The AN/ASA-13A

Navigational Computer Group AN/ASA-13A is an airborne dead reckoning computer which continuously determines displacement from an initial reference. Displacement is computed in E-W and N-S coordinates from information obtained from within the aircraft. These coordinates, in the form of d-c voltages, are used to displace CRT sweep origins for ground stabilized PPI displays.

The computer (fig. 11-9) resolves and combines voltages representing the airspeed and wind vectors. The resultant ground velocity (in component form) is then integrated to provide an indication of N-S and E-W ground displacement (distance) from an initial reference

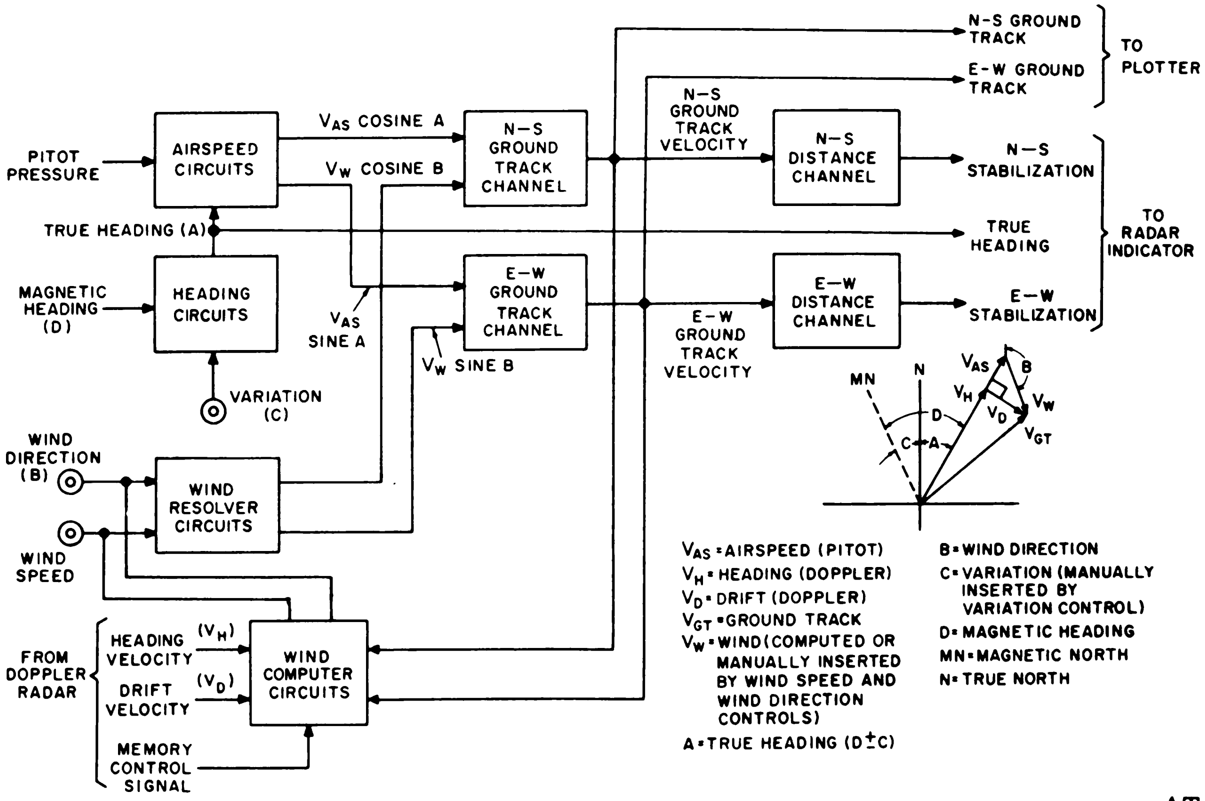


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Figure 11-9.—AN/ASA-13A, block diagram.

point. Inputs of magnetic heading and pitot pressure are automatically and continuously supplied from aircraft instruments. By manually inserting local variation, magnetic heading is changed to true heading. Pitot pressure is converted to airspeed data. The airspeed vector, defined by airspeed and true heading, is resolved into N-S and E-W components. The wind vector is similarly resolved and combined with the components of airspeed to provide ground track data.

The wind vector may be obtained from the Doppler radar system (when operating) or from the Doppler radar's memory circuit (when not tracking), or it may be manually inserted when the Doppler radar is not operating.

The OA-1768/ASA-13

Display-Plotting Board Group OA-1768/ASA-13 is a short-range airborne navigational device used to display ground track of the aircraft and target position data. It is used in conjunction with the AN/ASA-13 or -13A and a search radar system to provide a readily available view of the overall tactical situation. It is used during ASW or AEW maneuvers to provide an accurate reference on which to base tactical decisions.

The plotting board may be used to indicate as well as record the following:

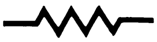
1. The position of the aircraft with respect to a preselected origin.
2. The position of a target relative to a remote reference point.
3. The present position of the aircraft and its position relative to the target.

The display, in the form of an illuminated arrow (called the crab), is continuously oriented to correspond to aircraft heading and ground track. The crab is driven by servomechanisms in response to N-S snd E-W data supplied by the navigational computer.

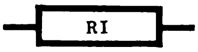
APPENDIX I

ELECTRONIC SYMBOLS

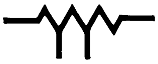
RESISTORS:



OR



GENERAL



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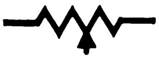
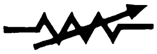
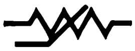


ADJUSTABLE TAP

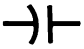


CONTINUOUSLY VARIABLE

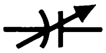


NONLINEAR

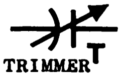
CAPACITORS:



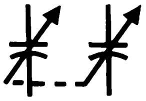
FIXED



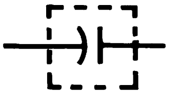
VARIABLE



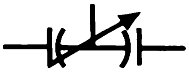
TRIMMER



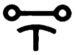
GANGED



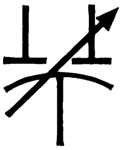
SHIELDED



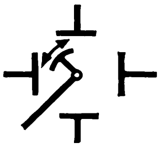
SPLIT-STATOR



FEED-THROUGH



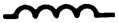
DIFFERENTIAL



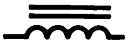
PHASE SHIFT

(WHEN CAPACITOR ELECTRODE IDENTIFICATION IS NECESSARY, THE CURVED ELEMENT SHALL REPRESENT THE OUTSIDE ELECTRODE IN FIXED PAPER-DIELECTRIC AND CERAMIC-DIELECTRIC, THE NEGATIVE ELECTRODE IN ELECTROLYTIC CAPACITORS, THE MOVING ELEMENT IN VARIABLE AND ADJUSTABLE CAPACITORS, AND THE LOW POTENTIAL ELEMENT IN FEED-THROUGH CAPACITORS.)

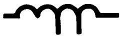
INDUCTIVE COMPONENTS:



GENERAL



MAGNETIC CORE



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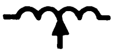
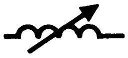
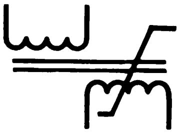


ADJUSTABLE

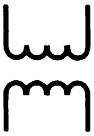


ADJUSTABLE OR CONTINUOUSLY ADJUSTABLE

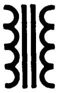


SATURABLE CORE REACTOR

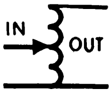
TRANSFORMERS



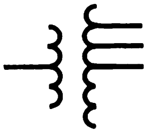
GENERAL



MAGNETIC CORE TRANSFORMER

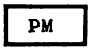


AUTOTRANSFORMER

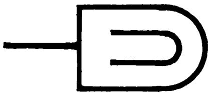


WITH TAPS, SINGLE-PHASE

PERMANENT MAGNET



INDICATOR LAMP



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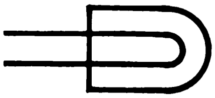
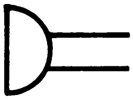


MICROPHONE



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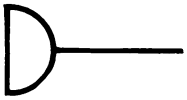
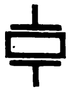
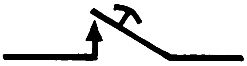


CRYSTAL



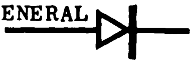
QUARTZ CRYSTAL;
PIEZOELECTRIC CRYSTAL
UNIT.

KEY

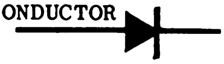


RECTIFIER

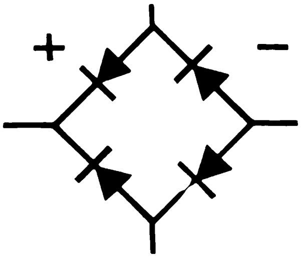
GENERAL



SEMICONDUCTOR

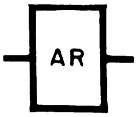


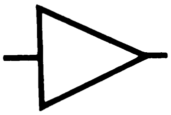
NORMAL CURRENT FLOW IS AGAINST THE ARROW



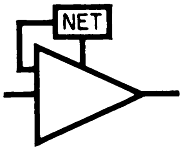
FULL WAVE BRIDGE TYPE

AMPLIFIER





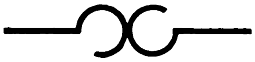
TRIANGLE POINTS
IN DIRECTION OF
TRANSMISSION
(SIGNAL FLOW)



AMPLIFIER WITH
EXTERNAL
FEEDBACK PATH

BASIC SYMBOL INDICATES ANY METHOD OF AMPLIFICATION EXCEPT THAT OPERATING ON THE PRINCIPLE OF ROTATING MACHINERY.

THERMAL ELEMENTS



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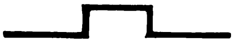
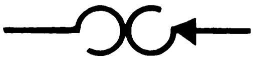


THERMAL RELAY WITH
NORMALLY CLOSED
CONTACT.



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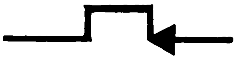
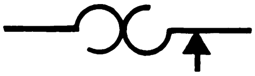


FLASHER; THERMAL CUTOUT



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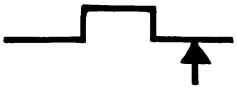
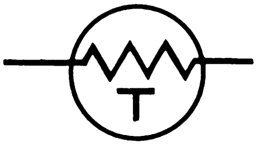
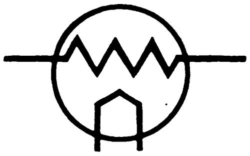
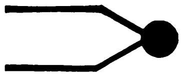




THERMISTOR

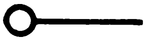


WITH INTEGRAL
HEATING ELEMENT



TEMPERATURE-MEASURING THERMOCOUPLE
(DISSIMILAR METAL DEVICE)

INPUTS (NONSTANDARD)



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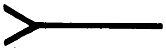
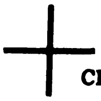
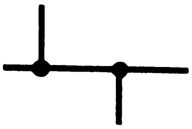


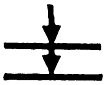
PATH, TRANSMISSION



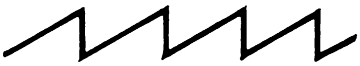
CROSSING NOT
CONNECTED



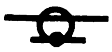
JUNCTION CONNECTED



TWISTED PAIR

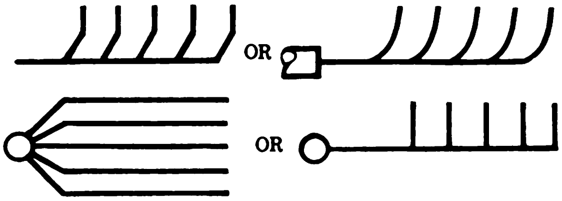


AIR OR SPACE PATH



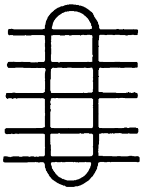
COAXIAL

GROUPING OF WIRES IN BUNDLES

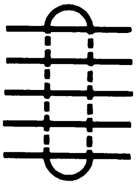


GROUPING OF WIRES IN CABLES

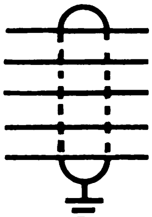
CABLES



FIVE-
CONDUCTOR
CABLE



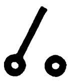
SHIELDED
FIVE-CONDUCTOR
CABLE



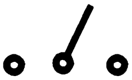
GROUNDED
SHIELD

NUMBER OF CONDUCTORS MAY BE ONE
OR MORE AS NECESSARY

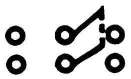
SWITCHES



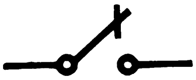
GENERAL
(SINGLE THROW)



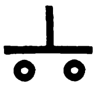
GENERAL
(DOUBLE THROW)



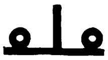
TWO POLE
DOUBLE THROW
SWITCH



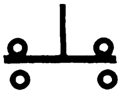
KNIFE SWITCH



PUSHBUTTON
(MAKE)

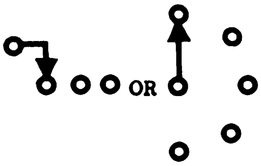


PUSHBUTTON
(BREAK)



PUSHBUTTON TWO CIRCUIT

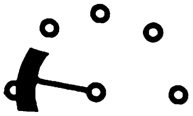
SELECTOR SWITCHES

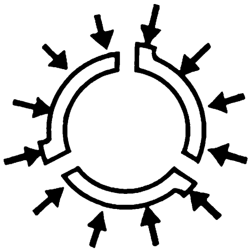


GENERAL

ANY NUMBER OF TRANSMISSION
PATHS MAY BE SHOWN. ALSO
BREAK BEFORE MAKE SWITCH.

**MAKE BEFORE
BREAK**

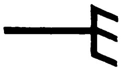




WAFER, TYPICAL 3-POLE, 3-CIRCUIT
SWITCH. VIEWED FROM END OPPOSITE
CONTROL KNOB. FOR MORE THAN ONE
SECTION, #1 IS NEAREST CONTROL
KNOB.

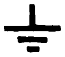
CIRCUIT RETURNS

CHASSIS CONNECTION



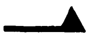
(THE CHASSIS OR
FRAME IS NOT
NECESSARILY AT
GROUND POTENTIAL.)

GROUND

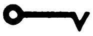


CONTACTS (ELECTRICAL)

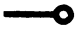
SWITCH



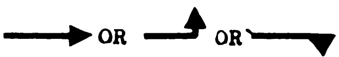
MOMENTARY
SWITCH



LOCKING



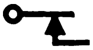
NONLOCKING



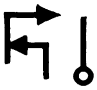
FOR JACK, KEY,
RELAY, ETC.

CONTACTS (ELECTRICAL) (Continued)

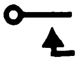
CONTACT ASSEMBLIES



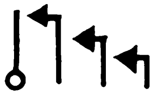
CLOSED CONTACT
(BREAK)

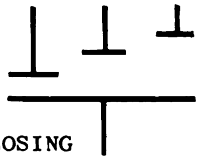


MAKE BEFORE
BREAK



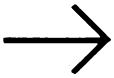
OPEN CONTACT
(MAKE)



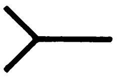


TIME SEQUENCE CLOSING

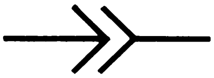
DISCONNECTING DEVICES



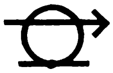
MALE
(PIN CONTACT)



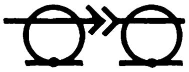
FEMALE
(SOCKET CONTACT)



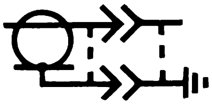
ENGAGED
(PIN-TO-SOCKET)



COAXIAL
(MALE)

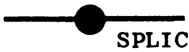


COAXIAL CONNECTORS
MATED

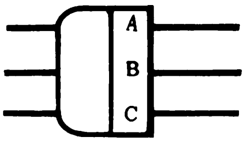


COAXIAL CONNECTED
TO SINGLE CONDUCTOR

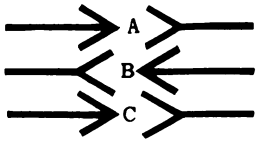
THE CONNECTOR SYMBOL IS NOT AN ARROWHEAD. IT IS LARGER AND THE LINES ARE DRAWN AT A 90° ANGLE.



SPLICE



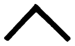
OR



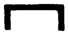
CONNECTOR ASSEMBLY (GENERAL)

ELECTRON TUBES

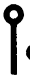
COMPONENT TUBE SYMBOLS



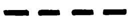
DIRECTLY-HEATED
(FILAMENTARY)
CATHODE



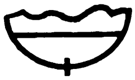
INDIRECTLY-HEATED
CATHODE



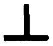
COLD
CATHODE



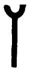
GRID



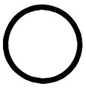
POOL CATHODE



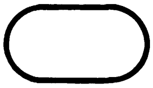
ANODE OR
PLATE



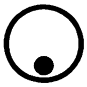
PHOTOCATHODE



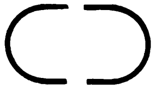
OR



ENVELOPE (SHELL)

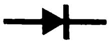


GAS FILLED
ENVELOPE

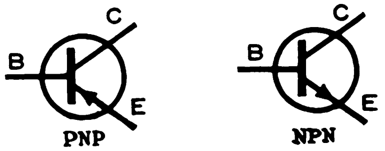


SPLIT ENVELOPE

SEMICONDUCTOR DEVICES



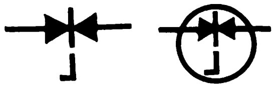
DIODE



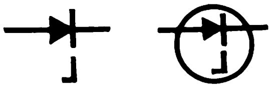
PNP

NPN

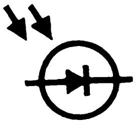
TRANSISTORS



BREAKDOWN DIODE,
BIDIRECTIONAL

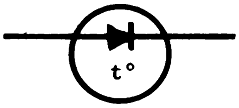


BREAKDOWN DIODE,
UNIDIRECTIONAL
(ALSO BACKWARD DIODE)

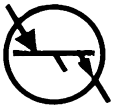


PHOTODIODE

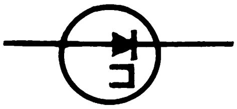
SEMICONDUCTOR DEVICES: (Continued)



TEMPERATURE
DEPENDENT DIODE

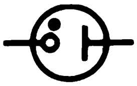


PNPN SWITCH

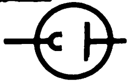


TUNNEL DIODE

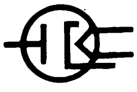
TYPICAL ELECTRON TUBES



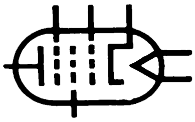
COLD CATHODE
GAS TUBE



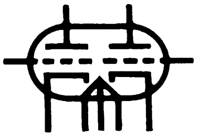
PHOTOTUBE SINGLE
UNIT, VACUUM



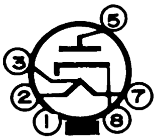
DIODE



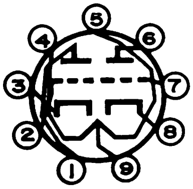
PENTODE



TWIN TRIODE
ILLUSTRATING
ELONGATED ENVELOPE

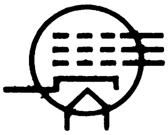


DIODE SHOWING BASE
CONNECTIONS

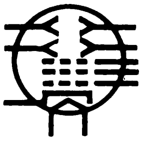


TWIN TRIODE WITH TAPPED HEATER

TYPICAL CATHODE RAY TUBES

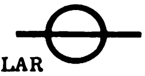


MAGNETIC DEFLECTION

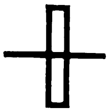


ELECTROSTATIC
DEFLECTION

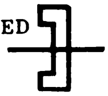
WAVEGUIDES



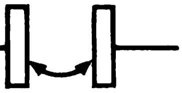
CIRCULAR



RECTANGULAR

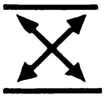


RIDGED

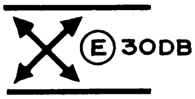


ROTARY
JOINT

DIRECTIONAL COUPLERS



GENERAL

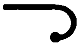


E PLANE APERTURE
COUPLING, 30 DB
TRANSMISSION LOSS

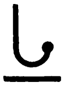
COUPLING METHODS

GENERALLY USED FOR COAXIAL AND WAVEGUIDE TRANSMISSION.

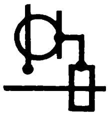
COUPLING BY APERTURE WITH AN OPENING OF LESS THAN FULL WAVEGUIDE SIZE. TYPE OF COUPLING WILL BE INDICATED WITHIN CIRCLE (E, H, OR HE).



COUPLING BY LOOP TO SPACE

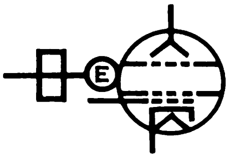


COUPLING BY LOOP TO GUIDED TRANSMISSION PATH



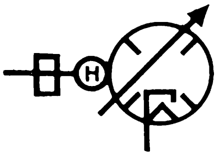
COUPLING BY PROBE FROM COAXIAL TO RECTANGULAR WAVEGUIDE WITH DIRECT-CURRENT GROUNDS CONNECTED

TYPICAL MAGNETRONS AND KLYSTRONS

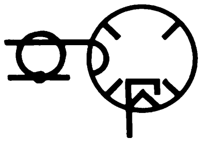


REFLEX KLYSTRON,
APERATURE COUPLED

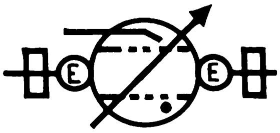
TUNABLE MAGNETRON,
APERTURE COUPLED



TYPICAL MAGNETRONS AND KLYSTRONS (Continued)

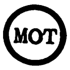


RESONANT TYPE WITH COAXIAL OUTPUT

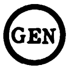


TRANSMIT-RECEIVE (TR) TUBE GAS FILLED, TUNABLE INTEGRAL CAVITY, APERTURE COUPLED, WITH STARTER

ROTATING MACHINES

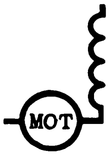


MOTOR

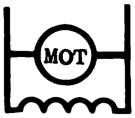


GENERATOR

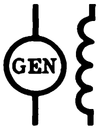
TYPES OF WINDINGS



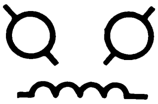
SERIES



SHUNT

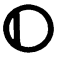


SEPARATELY EXCITED

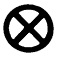


DYNAMOTOR

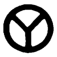
WINDING SYMBOLS



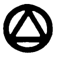
SINGLE-PHASE



TWO - PHASE



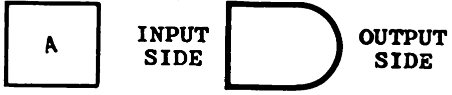
THREE-PHASE (WYE)



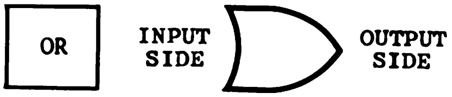
THREE-PHASE (DELTA)

LOGIC FUNCTIONS

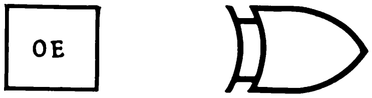
AND FUNCTION



INCLUSIVE OR FUNCTION

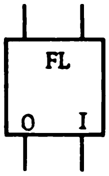


EXCLUSIVE OR FUNCTION

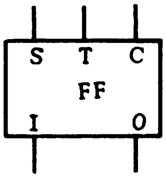


FLIP-FLOPS

LATCH



COMPLEMENTARY

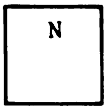


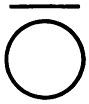
S-SET **T-TRIGGER** **C-CLEAR**

NEGATION

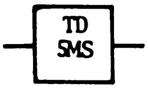
O

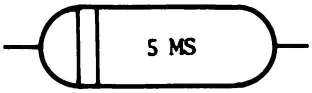
ELECTRIC INVERTER

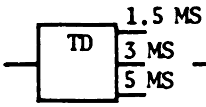


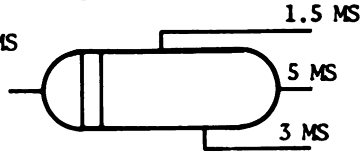


TIME DELAY



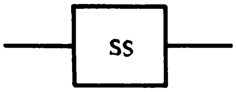




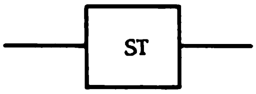


LOGIC FUNCTIONS (Continued)

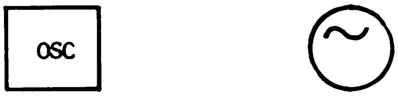
SINGLE SHOT



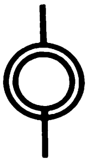
SCHMITT TRIGGER



OSCILLATOR



SYNCHROS

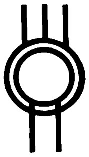


GENERAL

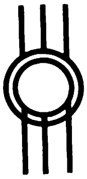
A LETTER COMBINATION FROM THE FOLLOWING LIST MAY BE PLACED ADJACENT TO THE SYMBOL TO INDICATE THE TYPE OF SYNCHRO:

TX - TORQUE TRANSMITTER
TDX - TORQUE DIFFERENTIAL TRANSMITTER
CX - CONTROL TRANSMITTER
CDX - CONTROL DIFFERENTIAL TRANSMITTER
TR - TORQUE RECEIVER
CT - CONTROL TRANSFORMER

SYNCHROS (Continued)

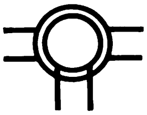


TRANSMITTER, RECEIVER, OR CONTROL TRANSFORMER

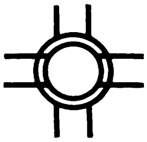


DIFFERENTIAL TRANSMITTER OR RECEIVER

RESOLVER (SYNCHRO)

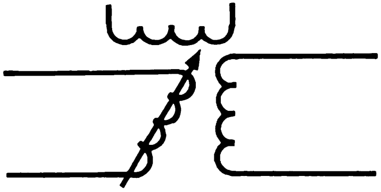


SINGLY-WOUND ROTOR

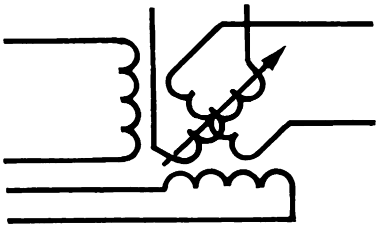


DOUBLY-WOUND ROTOR

RESOLVER

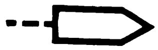


SINGLY-WOUND ROTOR

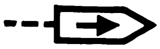


DOUBLY-WOUND ROTOR

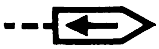
PICKUP HEADS



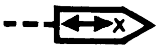
GENERAL



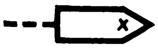
WRITING; RECORDING; HEAD,
SOUND RECORDER



READING; PLAYBACK; HEAD,
SOUND REPRODUCER

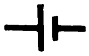


APPLICATION: WRITING, READING,
AND ERASING

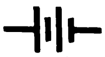


ERASING; ERASER, MAGNETIC

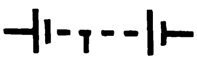
BATTERIES



ONE CELL



MULTICELL

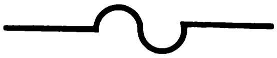


TAPPED
MULTICELL

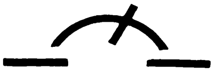
(LONG LINE IS ALWAYS POSITIVE)

CIRCUIT PROTECTORS

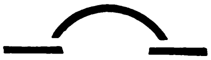
FUSE



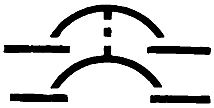
CIRCUIT BREAKERS



SWITCH

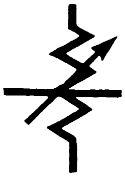


PUSH PULL OR PUSH

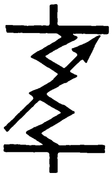


GANGED

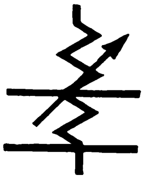
ATTENUATORS



GENERAL



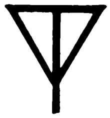
BALANCED



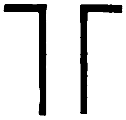
UNBALANCED

ANTENNAS

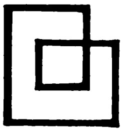
GENERAL



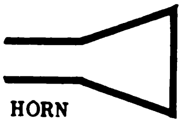
DIPOLE



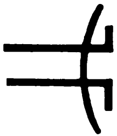
PARABOLIC



LOOP

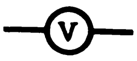


HORN



(NONSTANDARD)

METERS



A - AMMETER

CRO - OSCILLOSCOPE

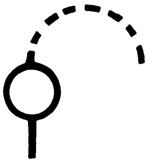
G - GALVANOMETER

MA - MILLIAMMETER

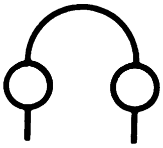
OHM - OHMMETER

V - VOLTMETER

HEADSET



OR



APPENDIX II

GREEK ALPHABET

Name	Capital	Lower Case	Designates
Alpha	A	α	Angles.
Beta	B	β	Angles, flux density.
Gamma . . .	Γ	γ	Conductivity.
Delta	Δ	δ	Variation of a quantity, increment.
Epsilon . . .	E	ϵ	Base of natural logarithms (2.71828).
Zeta	Z	ζ	Impedance, coefficients, coordinates.
Eta	H	η	Hysteresis coefficient, efficiency, magnetizing force.
Theta	Θ	θ	Phase angle.
Iota	I	ι	
Kappa	K	κ	Dielectric constant, coupling coefficient, susceptibility.
Lambda . . .	Λ	λ	Wavelength.
Mu	M	μ	Permeability, micro, amplification factor.
Nu	N	ν	Reluctivity.
Xi	Ξ	ξ	
Omicron . . .	O	o	
Pi	Π	π	3.1416
Rho	P	ρ	Resistivity.
Sigma	Σ	σ	
Tau	T	τ	Time constant, time-phase displacement.
Upsilon . . .	Υ	υ	
Phi	Φ	φ	Angles, magnetic flux.
Chi	X	χ	
Psi	Ψ	ψ	Dielectric flux, phase difference.
Omega	Ω	ω	Ohms (capital), angular velocity ($2 \pi f$).

APPENDIX III

FORMULAS

Ohm's Law for D-C Circuits

$$I = \frac{E}{R} = \frac{P}{E} = \sqrt{\frac{P}{R}}$$

$$R = \frac{E}{I} = \frac{P}{I^2} = \frac{E^2}{P}$$

$$E = IR = \frac{P}{I} = \sqrt{PR}$$

$$P = EI = \frac{E^2}{R} = I^2R$$

Resistors in Series

$$R_T = R_1 + R_2 + \ldots$$

Resistors in Parallel

Two resistors

$$R_T = \frac{R_1R_2}{R_1 + R_2}$$

More than two

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

RL Circuit Time Constant

$$\frac{L \text{ (in henrys)}}{R \text{ (in ohms)}} = t \text{ (in seconds), or}$$

$$\frac{L \text{ (in microhenrys)}}{R \text{ (in ohms)}} = t \text{ (in microseconds)}$$

RC Circuit Time Constant

R (ohms) x C (farads) = t (seconds)

R (megohms) x C (microfarads) = t (seconds)

R (ohms) x C (microfarads) = t (microseconds)

R (megohms) x C (micromicrofarads) = t (microseconds)

Capacitors in Series

Two capacitors

$$C_T = \frac{C_1C_2}{C_1 + C_2}$$

More than two

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

Capacitors in Parallel: $C_T = C_1 + C_2 + \ldots$

Capacitive Reactance: $X_C = \frac{1}{2\pi fC}$

Impedance in an RC Circuit (Series)

$$Z = \sqrt{R^2 + (X_C)^2}$$

Inductors in Series

$L_T = L_1 + L_2 + \ldots$ (No coupling between coils)

Inductors in Parallel

Two inductors

$L_T = \frac{L_1L_2}{L_1 + L_2}$ (No coupling between coils)

More than two

$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots$ (No coupling between coils)

Inductive Reactance

$$X_L = 2\pi fL$$

Q of a Coil

$$Q = \frac{X_L}{R}$$

Impedance of an RL Circuit (Series)

$$Z = \sqrt{R^2 + (X_L)^2}$$

Impedance with R, C, and L in Series

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Parallel Circuit Impedance

$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

Sine-Wave Voltage Relationships

Average value

$$E_{ave} = \frac{2}{\pi} \text{ x } E_{max} = 0.637E_{max}$$

Effective or r.m.s. value

$$E_{eff} = \frac{E_{max}}{\sqrt{2}} = \frac{E_{max}}{1.414} = 0.707E_{max}$$
$$= 1.11E_{ave}$$

Maximum value

$$E_{max} = \sqrt{2}(E_{eff}) = 1.414E_{eff}$$
$$= 1.57E_{ave}$$

Voltage in an a-c circuit

$$E = IZ = \frac{P}{I \text{ x } P.F.}$$

Current in an a-c circuit

$$I = \frac{E}{Z} = \frac{P}{E \text{ x } P.F.}$$

Power in A-C Circuit

Apparent power: $P = EI$

True power: $P = EI \cos \theta = EI \text{ x } P.F.$

Power Factor

$$P.F. = \frac{P}{EI} = \cos \theta$$

$$\cos \theta = \frac{\text{true power}}{\text{apparent power}}$$

Transformers

Voltage relationship

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \text{ or } E_s = E_p \text{ x } \frac{N_s}{N_p}$$

Current relationship

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Induced voltage

$$E_{eff} = 4.44 \text{ x } BAfN \text{ x } 10^{-8}$$

Turns ratio

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

Secondary current

$$I_s = I_p \text{ x } \frac{N_p}{N_s}$$

Secondary voltage

$$E_s = E_p \text{ x } \frac{N_s}{N_p}$$

Three-Phase Voltage and Current Relationships

With wye connected windings

$$E_{line} = \sqrt{3}(E_{coil}) = 1.732E_{coil}$$

$$I_{line} = I_{coil}$$

With delta connected windings

$$E_{line} = E_{coil}$$

$$I_{line} = 1.732I_{coil}$$

With wye or delta connected winding

$P_{coil} = E_{coil} I_{coil}$

$P_t = 3P_{coil}$

$P_t = 1.732 E_{line} I_{line}$

(To convert to true power multiply by cos θ)

Resonance

At resonance

$X_L = X_C$

Resonant frequency

$$F_o = \frac{1}{2\pi\sqrt{LC}}$$

Series resonance

Z (at any frequency) $= R + j(X_L - X_C)$

Z (at resonance) $= R$

Parallel resonance

$$Z_{max} \text{ (at resonance)} = \frac{X_L X_C}{R} = \frac{X_L^2}{R}$$

$$= QX_L = \frac{L}{CR}$$

Band width

$$\Delta = \frac{F_o}{Q} = \frac{R}{2\pi L}$$

Tube Characteristics

Amplification factor

$$\mu = \frac{\Delta e_p}{\Delta e_g} \text{ } (i_p \text{ constant})$$

$$\mu = g_m r_p$$

A-c plate resistance

$$r_p = \frac{\Delta e_p}{\Delta i_p} \text{ } (e_g \text{ constant})$$

Grid-plate transconductance

$$g_m = \frac{\Delta i_p}{\Delta e_g} \text{ } (e_p \text{ constant})$$

Decibels

NOTE: Wherever the expression "log" appears without a subscript specifying the base, the logarithmic base is understood to be 10.

Power ratio

$$db = 10 \log \frac{P_2}{P_1}$$

Current and voltage ratio

$$db = 20 \log \frac{I_2 \sqrt{R_2}}{I_1 \sqrt{R_1}}$$

$$db = 20 \log \frac{E_2 \sqrt{R_1}}{E_1 \sqrt{R_2}}$$

NOTE: When R_1 and R_2 are equal they may be omitted from the formula. When reference level is one milliwatt

$$dbm = 10 \log \frac{P}{0.001} \text{ (when P is in watts)}$$

Synchronous Speed of Motor

$$\text{r.p.m.} = \frac{120 \text{ x frequency}}{\text{number of poles}}$$

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